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THE DEEP BORING AT SPUR

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BY

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INTRODUCTORY NOTE

In the northwest part of the State, east of the Pecos, the formations lie nearly horizontal. This structure prevails over the entire Plains, extending from the north end of the Panhandle to a line joining San Angelo and Pecos on the south. This area measures 330 miles from north to south and 170 miles from east to west. The deeper lying rocks can hence be known here only from inferences based on their appearance in distant outcrops outside of this area and from such local observations as may be obtained from deep explorations. It is singularly fortunate for our knowledge of the stratigraphy of this part of the continent that a deep boring was made at a point not far from the central part of the area defined. The exploration enables us to know by actual observation what strata underlie. It will enable us to say with greater accuracy what other borings will penetrate even at considerable distances from this exploration. It furnishes firsthand information on the stratigraphy of this part of the State. While this paper describes the section of a single boring, it really gives the only facts so far known concerning the deep stratigraphy of a region covering one-fifth of the area of this State.

HISTORY

The deepest boring in Texas is now (1914) at Spur, in Dickens county, south of the east portion of the Panhandle. This boring has been made by large landholders in this and adjoining counties, in search of water for the town of Spur, and as a general exploration of the formations for the

vicinity. Spur is the present northwest terminus of the Stamford & Northwestern Railway. The boring is located about a half mile southeast from the railroad station, with the curb at 2335.4 A.T.

Work on this well was begun in June, 1909. The drilling rig had been hauled overland from Rotan, in Fisher county, which was at that time the nearest railroad point to the Spur Ranch. All the work was done with a rotary machine, and Mr. H. P. Minihan, who was engaged as driller, continued in charge throughout the entire operation. The hole was abandoned and wrecked in November, 1913, at the depth of 4489 feet. The cost of the boring was slightly more than ten dollars a foot, or nearly $50,000.00, including the cost of the rig, piping and all expenses. The salvage brought the net expense down to about $45,000.00.

The first serious difficulty encountered in this work was the caving of sand at the depth of sixty feet. This was remedied by setting a ten-inch casing at 60 feet and 6 inches. Later it was found necessary to set an eight-inch casing at 476 feet, a six-inch casing at 1357 feet, and a four-inch casing at 3044 feet. From this last depth to the bottom the hole was not cased, and the drilling through the four-inch casing was done with a three and seven-eighths-inch bit.

Mr. C. A. Jones, the manager for the company, under whose directions the work was done, writes concerning the undertaking as follows:

"The remarkable feature of the boring was the continuity and the persistency of the rock. The log will show what a tremendous bed of rock was penetrated. At different times, due to imperfect method of securing cones to the drillhead, in the roller bit, cones were lost in the well, giving us serious fishing troubles. The final failure was due to this cause. A cone was lost in the well and in attempting to go after it, the fishing line was lost in the well, probably owing to caving. It was impossible to free it, and after several months of attempts, with every variety of fishing tool that could be suggested, the well was abandoned. It is a matter of great regret that we were compelled to

abandon this well, but it was something of an achievement to have made the deepest exploration in the state."

Through the kindness of Mr. W. E. Wrather, the writer's attention was first called to the work on this boring in the latter part of December, 1911, when it had reached a depth of 2600 feet. We jointly made a visit to Spur and secured a log of the ground explored. I also examined some pieces of core, which had been taken and preserved. Arrangements were at the same time made with the manager, Mr. C. A. Jones, to furnish to the Bureau of Economic Geology and Technology cuttings from all depths possible. It is due to the generous policy in this matter on the part of Mr. Jones that it is now possible to describe in considerable detail the strata penetrated and to verify and correctly interpret the long record, which was kept with more than usual care by the driller, Mr. H. P. Minihan.

Acknowledgments

The detailed examination of a large number of samples, which consumed much time, was in part made possible by the assistance of the U. S. Geological Survey, for which the writer wishes to express his obligations. The same survey has also kindly made all but one of the photographs for the plates of this bulletin.

The Driller's Record

		Feet below surface. From.	To.	Thickness.
1.	Brown soil	0	2	2
2.	White porous material	2	6	4
3.	Yellow sand	6	16	10
4.	Sand and gravel, water	16	23	7
5.	Hard concrete of light color	23	27	4
6.	Tough red clay	27	53	26
7.	Hard concrete	53	65	12
8.	Isinglass (selenite) and red clay	65	75	10
9.	Hard, flinty rock	75	85	10
10.	Red clay and red sand rock	85	98	13
11.	White chalky rock	98	101	3

		Feet below surface. From.	To.	Thick-ness.
12.	Isinglass (selenite)	101	108	7
13.	Red clay and red sand rock	108	115	7
14.	Isinglass (selenite)	115	119	4
15.	Red sand rock, thick streak of red clay	119	135	16
16.	Red clay, thin streak of blue clay	135	137	2
17.	Red clay and sand rock	137	149	12
18.	Red clay and isinglass (selenite)	149	153	4
19.	Red sand and clay	153	192	39
20.	Isinglass (selenite)	192	199	7
21.	Red gumbo	199	221	22
22.	Isinglass (selenite) and gypsum	221	223	2
23.	Red gumbo	223	239	16
24.	Isinglass (selenite)	239	254	15
25.	Soft red sand rock	254	272	18
26.	Soft red clay	272	285	13
27.	White flinty rock and isinglass (selenite)	285	298	13
28.	Sand, salt water	298	330	32
29.	White flinty rock	330	403	73
30.	Red sand rock	403	468	65
31.	Hard gray sand, and red sand	468	532	64
32.	Soft white clay	532	538	6
33.	White hard flinty rock	538	540	2
34.	White tough rock	540	568	28
35.	Hard white flinty rock	568	570	2
36.	Salt rock	570	580	10
37.	Brown sand rock	580	586	6
38.	Hard white flinty rock	586	596	10
39.	Brown sand rock	596	603	7
40.	Tough white rock	603	624	21
41.	Hard white flinty rock	624	628	4
42.	Hard brown sand rock	628	633	5
43.	Salt rock. No sample	633	638	5
44.	Light soft rock	638	645	7
45.	Hard sand rock	645	674	29
46.	Notes wanting	674	688	14
47.	Hard sand rock	688	715	27
48.	Soft sand rock	715	725	10
49.	Soft white rock, hard in streaks	725	732	7
50.	Salt rock	732	741	9
51.	Hard concrete sand rock	741	773	32
52.	White flinty rock	773	778	5
53.	Concrete sand rock	778	804	26
54.	Sand rock and red gumbo	804	812	8

		Feet below surface. From.	To.	Thick- ness.
55.	White flinty rock	812	816	4
56.	Red sand rock	816	853	37
57.	White flinty rock	853	858	5
58.	Red sand rock	858	931	73
59.	Hard blue rock	931	932	1
60.	Notes wanting	932	958	26
61.	Red sand rock	958	1113	155
62.	Gray lime	1113	1117	4
63.	Red sand rock	1117	1123	6
64.	Gray lime rock	1123	1125	2
65.	Red sand rock	1125	1174	49
66.	Soft white rock	1174	1222	48
67.	Gray lime rock	1222	1235	13
68.	Soft white rock	1235	1250	15
69.	Hard gray rock	1250	1252	2
70.	Hard limestone	1252	1270	18
71.	Very hard lime rock	1270	1272	2
72.	Hard limestone	1272	1302	30
73.	Very hard limestone	1302	1309	7
74.	Hard limestone	1309	1313	4
75.	Hard blue rock	1313	1327	14
76.	Hard limestone	1327	1335	8
77.	Blue rock	1335	1337	2
78.	Hard limestone	1337	1341	4
79.	Somewhat soft limestone	1341	1347	6
80.	Very hard limestone	1347	1349	2
81.	Lime and blue rock	1349	1364	15
82.	Hard lime rock	1364	1370	6
83.	Blue lime rock	1370	1376	6
84.	Hard lime rock	1376	1390	14
85.	Limestone	1390	1391	1
86.	Hard limestone	1391	1397	6
87.	Hard limestone with soft blue streaks	1397	1403	6
88.	Hard limestone	1403	1419	16
89.	Lime rock	1419	1425	6
90.	Hard lime rock with soft streaks	1425	1433	8
91.	Hard lime rock	1433	1454	21
92.	Hard lime rock with soft streaks	1454	1461	7
93.	Hard limestone	1461	1478	17
94.	Very hard rock	1478	1483	5
95.	Hard rock	1483	1502	19
96.	Sand rock, fossils	1502	1503	1
97.	Blue rock	1503	1506	3

		Feet below surface. From.	To.	Thick-ness.
98.	Sand, lime, and blue rock	1506	1510	4
99.	Hard blue rock	1510	1514	4
100.	Blue and gray rock	1514	1520	6
101.	Hard gray rock	1520	1523	3
102.	Very hard gray rock	1523	1525	2
103.	Hard gray rock	1525	1538	13
104.	Blue and gray sand rock	1538	1546	8
105.	Blue sandy and slaty rock	1546	1551	5
106.	Blue sandy rock	1551	1554	3
107.	Hard gray rock	1554	1555	1
108.	Gray and blue hard rock	1555	1558	3
109.	Hard gray rock	1558	1560	2
110.	Hard gray and blue rock	1560	1563	3
111.	Very hard gray rock	1563	1575	12
112.	Very hard gray flinty rock	1575	1579	4
113.	Gray, blue, and yellow rock	1579	1581	2
114.	Hard blue rock	1581	1595	14
115.	Gray and blue rock	1595	1599	4
116.	Blue rock	1599	1600	1
117.	Hard gray rock	1600	1619	19
118.	Gray and blue rock	1619	1631	12
119.	Hard blue rock	1631	1639	8
120.	Hard blue and gray rock	1639	1645	6
121.	Hard gray rock	1645	1651	6
122.	Very hard gray rock	1651	1655	4
123.	Hard gray rock	1655	1668	13
124.	Blue and gray rock	1668	1676	8
125.	Hard blue rock	1676	1688	12
126.	Gray and blue rock	1688	1703	15
127.	Very hard flinty blue rock	1703	1704	1
128.	Very hard sand rock above and then very hard sand and flint rock. Very rough. Rock seemed to have a split in it	1704	1705	1
129.	Gray rock. (Mr. W. E. Wrather, who examined this piece of core, describes it as a rough-grained, hard cemented sand rock)	1705	1707	2
130.	Hard blue and gray rock	1707	1730	23
131.	Very hard blue flinty rock	1730	1738	8
132.	Hard blue rock	1738	1741	3
133.	Hard blue and gray rock	1741	1780	39
134.	Hard flinty rock	1780	1783	3
135.	Hard gray and blue rock	1783	1794	11

		Feet below surface. From.	To.	Thick-ness.
136.	Hard blue rock	1794	1799	5
137.	Hard blue and gray rock	1799	1803	4
138.	Hard gray rock, quit in very hard sand rock	1803	1805	2
139.	Very hard sand rock. Had split in it. Very rough	1805	1806	1
140.	Upper six inches very hard sandy, flinty rock, rough; had crack in it. Lower two and a half feet is very hard blue flinty sand rock	1806	1809	3
141.	Very hard blue sand rock	1809	1810	1
142.	Hard blue rock	1810	1816	6
143.	Hard gray and blue rock. Quit in flint at 1823	1816	1823	7
144.	Very hard sand and flint rock	1823	1824	1
145.	Hard sand and flint	1824	1825	1
146.	Blue rock	1825	1826	1
147.	Hard flint rock	1826	1827	1
148.	Hard sand and flint rock in the upper six inches, then flint sand and blue rock	1827	1830	3
149.	Blue rock with flint at bottom	1830	1838	8
150.	Flint and blue rock	1838	1845	7
151.	Gray and blue rock	1845	1851	6
152.	Hard blue rock with streak of flint	1851	1855	4
153.	Gray and blue rock	1855	1860	5
154.	Hard gray sand and flint	1860	1862	2
155.	Very hard sand and flint and very rough sand and flint	1862	1863	1
156.	Flint and sand a few inches, then blue rock	1863	1864	1
157.	Blue rock	1864	1874	10
158.	Hard blue rock and flint rock	1874	1877	3
159.	Blue rock with sand and very hard flint rock in bottom	1877	1884	7
160.	Hard blue rock	1884	1898	14
161.	Gray and blue rock. Some sand in it	1898	1910	12
162.	Blue rock, not very hard	1910	1936	26
163.	Hard gray rock	1936	1938	2
164.	Very hard blue rock	1938	1952	14
165.	Flint and blue rock	1952	1955	3
166.	Blue rock	1955	1964	9
167.	Hard blue rock	1964	1969	5
168.	Blue and gray rock	1969	1975	6

		Feet below surface. From.	To.	Thickness.
169.	Hard gray and blue rock; 3 feet gray above, 2 feet blue below	1975	1980	5
170.	Hard gray and blue rock, gray rock and flint, and sand rock	1980	1988	8
171.	Very hard sand and blue rock	1988	1992	4
172.	Hard blue and gray rock	1992	2000	8
173.	Grayish blue and gray rock, with flint below	2000	2007	7
174.	Very hard flint and sand rock	2007	2008	1
175.	Flint and blue rock, very hard	2008	2011	3
176.	Very hard blue rock	2011	2014	3
177.	Gray and blue rock	2014	2027	13
178.	Hard gray rock with streaks of blue	2027	2032	5
179.	Hard blue rock with flint in lower part	2032	2036	4
180.	Hard blue rock with streaks of flint	2036	2041	5
181.	Hard blue rock	2041	2042	1
182.	Blue shale	2042	2047	5
183.	Soft red sand rock, water	2047	2049	2
184.	Blue and gray rock	2049	2050	1
185.	Hard gray and blue rock	2050	2059	9
186.	Very hard blue rock	2059	2063	4
187.	Flint	2063	2064	1
188.	Blue and gray rock	2064	2068	4
189.	Soft red sand rock, hard in streaks	2068	2107	39
190.	Red sand rock and hard gray lime rock	2107	2115	8
191.	Very hard gray limestone, almost flint	2115	2126	11
192.	Blue rock	2126	2128	2
193.	Gray, blue and red sand rock	2128	2131	3
194.	Hard red sand rock	2131	2162	31
195.	Red sand rock, not very hard	2162	2176	14
196.	Hard red sand rock	2176	2204	28
197.	Very hard sand rock	2204	2209	5
198.	Very hard red sand rock	2209	2211	2
199.	Hard blue lime and flint rock	2211	2214	3
200.	Very hard flint rock (three days' drilling)	2214	2216	2
201.	Very hard sand and flint rock (three days)	2216	2219	3
202.	Blue limestone	2219	2223	4
203.	Very hard flint and limestone	2223	2224	1
204.	Very hard limestone	2224	2226	2
205.	Very hard blue limestone and flint	2226	2236	10
206.	Very hard limestone and flint	2236	2239	3

		Feet below surface. From.	To.	Thick-ness.
207.	Very hard blue limestone and flint	2239	2240	1
208.	Very hard sand and flint rock	2240	2242	2
209.	Very hard sand rock	2242	2243	1
210.	Very hard sand and flint rock	2243	2244	1
211.	Sand in flint rock (core)	2244	2250	6
212.	Very hard sandstone (core), much pyrite near this depth reported by Minihan	2250	2270	20
213.	Hard blue lime rock (core)	2270	2274	4
214.	Blue limestone	2274	2276	2
215.	Red sandstone	2276	2278	2
216.	Hard lime rock	2278	2281	3
217.	Very hard lime rock	2281	2287	6
218.	Very hard limestone and flint	2287	2291	4
219.	Very hard blue lime rock	2291	2296	5
220.	Very hard lime rock	2296	2298	2
221.	Very hard lime rock and flint	2298	2300	2
222.	Hard lime and flint rock (six days' drilling)	2300	2307	7
223.	Very hard limestone and flint rock	2307	2312	5
224.	Very hard blue lime rock	2312	2322	10
225.	Hard blue lime rock	2322	2329	7
226.	Red sand rock	2329	2331	2
227.	Hard blue lime rock	2331	2333	2
228.	Very hard blue lime rock	2333	2343	10
229.	Very hard blue lime rock, almost flint	2343	2348	5
230.	Hard limestone	2348	2362	14
231.	Hard blue limestone	2362	2381	19
232.	Blue limestone	2381	2383	2
233.	Hard limestone	2383	2392	9
234.	Red sand rock and limestone	2392	2395	3
235.	Blue limestone	2395	2396	1
236.	Red sandstone and blue limestone	2396	2401	5
237.	Blue limestone	2401	2413	12
238.	Very hard limestone	2413	2416	3
239.	Blue limestone	2416	2429	13
240.	Hard limestone	2429	2442	13
241.	Blue limestone	2442	2450	8
242.	Lime and red sand rock	2450	2466	16
243.	Hard blue sand rock	2466	2472	6
244.	Blue sandstone and limestone	2472	2480	8
245.	Limestone	2480	2487	7
246.	Blue limestone	2487	2535	48
247.	Red sandstone and limestone	2541	2551	10

		Feet below surface. From.	To.	Thickness.
248.	Limestone	2551	2560	9
249.	Blue limestone	2560	2599	39
250.	Lime and red sandstone	2599	2612	13
251.	Blue limestone	2612	2622	10
252.	Lime and blue sandstone	2622	2640	18
253.	Blue sand and red sand rock	2640	2653	13
254.	Red sand and lime rock	2653	2664	11
255.	Soft red sand rock	2664	2673	9
256.	Blue limestone	2673	2677	4
257.	Blue shale	2677	2682	5
258.	Limestone	2682	2685	3
259.	Blue sand rock, very hard	2685	2694	9
260.	Blue sand rock	2694	2701	7
261.	Lime and brown sand rock	2701	2716	15
262.	Hard brown sand rock	2716	2735	19
263.	Brown sand rock	2735	2744	9
264.	Soft gray sand rock, hard streaks	2744	2751	7
265.	Brown sand rock, hard	2751	2802	51
266.	Brown sand rock	2802	2969	167
267.	Hard brown sand rock	2969	2975	6
268.	Very hard brown sand rock and flint	2975	2980	5
269.	Anhydrite, water seep	2980	2995	15
270.	Limestone	2995	3045	50
271.	Anhydrite	3045	3046	1
272.	Limestone	3046	3060	14
273.	Hard blue shale with streaks of lime	3060	3075	15
274.	Streaks of anhydrite and hard limestone	3075	3125	50
275.	Limestone, hard	3125	3141	16
276.	Limestone	3141	3180	39
277.	Brown limestone	3180	3185	5
278.	Limestone	3185	3200	15
279.	Limestone and anhydrite	3200	3205	5
280.	Limestone	3205	3210	5
281.	Limestone, very hard	3210	3215	5
282.	Limestone	3215	3240	25
283.	Limestone and anhydrite	3240	3245	5
284.	Limestone	3245	3255	10
285.	Brown limestone	3255	3260	5
286.	Limestone	3260	3280	20
287.	Brown limestone	3280	3290	10
288.	Limestone	3290	3320	30
289.	Limestone	3320	3340	20
290.	Brown limestone	3340	3345	5

		Feet below surface. From.	To.	Thick-ness.
291.	Limestone	3345	3350	5
292.	Brown limestone	3350	3355	5
293.	Limestone	3355	3363	8
294.	Very hard brown rock	3363	3371	8
295.	Limestone	3371	3512	141
296.	Very hard limestone	3512	3521	9
297.	Very hard brown limestone	3521	3540	19
298.	Limestone	3540	3667	127
299.	Blue shale	3667	3669	2
300.	Limestone	3669	3752	83
301.	Very flinty limestone	3752	3763	11
302.	Hard limestone	3763	3791	28
303.	Limestone	3791	3842	51
304.	Brown and hard limestone	3842	3850	8
305.	Very hard limestone	3850	3858	8
306.	Limestone	3858	3926	68
307.	Hard limestone and some pyrite	3926	3932	6
308.	Limestone with lot of pyrite	3932	3947	15
309.	Very hard limestone and pyrite	3947	3952	5
310.	Limestone	3952	3964	12
311.	Brown limestone with pyrite	3964	3975	11
312.	Limestone	3971	3986	15
313.	Limestone with pyrite	3986	3994	8
317.	Limestone	3994	4020	26
318.	Hard limestone	4020	4045	25
319.	Limestone	4045	4075	30
320.	Very hard limestone	4075	4076	1
321.	Limestone and anhydrite	4076	4088	12
322.	Gray limestone	4088	4152	64
323.	Very hard limestone	4152	4168	16
324.	Limestone	4168	4215	47
325.	Hard limestone	4215	4218	3
326.	Limestone	4218	4263	45
327.	Brown limestone	4263	4278	15
328.	Limestone	4278	4288	10
329.	Gray limestone	4288	4305	17
330.	Limestone	4305	4325	20
331.	Very hard limestone	4325	4332	7
332.	Hard limestone	4332	4350	18
333.	Limestone	4350	4389	39
334.	Limestone and shale	4389	4398	9
335.	Limestone, streaks, dark shale	4398	4407	9
336.	Dark shale and limestone	4407	4431	24

		Feet below surface. From.	To.	Thick-ness.
337.	Dark shale with streaks of limestone	4431	4470	39
338.	Limestone and dark shale	4470	4475	5
339.	Limestone	4475	4479	4
340.	Limestone and shale	4479	4489	10

EXPLANATION OF TERMS USED

The above record was kept in five standard diary books for the years the work was in progress by Mr. H. P. Minihan, the driller. In these he recorded not only the depth bored each day and the nature of the rock on which the drill was working, but also generally the hours of time consumed in actual drilling, the kind of bit used, and the many other operations incident to the actual drilling. All these records have been generously submitted to the writer. Mr. Minihan's record of the strata penetrated has been copied from his notes practically verbatim, with the mere elimination of repetitions incident to the making of daily entries.

Though being a driller of wide experience, Mr. Minihan had not worked in the Red Beds previous to his engagement at Spur. A few notes on the descriptive terms used in his entries may not be amiss. "Isinglass" is frequently used in the southwest for gypsum, especially when it is in the pure crystalline form of selenite. It is evident that the term is thus used here. "Gumbo" is "clay which adheres to the bit." The red clays so designated in this record had the same property, and they seem to have been marly. "Flinty," as used in the uppermost 1000 feet of the record, has reference to compactness of texture in anhydrite, except in number 9, where there were some flint and quartz pebbles. The compactness, the gray color, and the conchoidal fracture of some of the close-grained anhydrite gives to this rock a notable optical resemblance to flint, and chert, as this appears in the Edwards limestone and other parts of the Comanchean. Between 1600 and 2000 feet it is believed the descriptions "flinty rock," "flint rock," "flint," and "sand

flint," often refer to concretions and layers of tough chalcedonic quartz, which occur in association with anhydrite in some of the limestone penetrated. In number 211 and presumably in some preceding entries, the word "flint" is to be understood in its usual sense, as is shown by the samples. Between 2210 and 2200 feet below the surface, there was a siliceous dolomite, dark in color, which was very resistant to the drill. This may probably be most correctly described as a chert. In some other cases, the significance of the term flint is not so evident.

Throughout most of the first 2000 feet of this record the qualifying word "hard" is generally used to denote moderate induration in distinction from the soft unindurated state of such rocks as sand, clay, marl and shale. Especially is this true when the term is applied to limestone. "Very hard" is then used to describe more than normal hardness. When used to describe sandstone and shale, the term "hard" is evidently used to distinguish particular strata of these sediments from others of the same kind which were less indurated. In this sense it appears to be used also when applied to limestone in the last 2000 feet of the section. "Flint sand" and "sand and flint rock" are two unusual and, in one sense, contradictory terms describing a somewhat unusual kind of rock, consisting of dolomite, into which have been introduced anhydrite and some siliceous material. It is believed that the oolitic character of part of this limestone has naturally caused it to be classified as sandstone or sand rock. This appears to be the case with the sandstone in number 212, and it may explain some of the difference between the driller's record and the samples described from between 2800 and 3050 feet in the section.

METHODS AND RATE OF DRILLING

The drilling was performed by a rotary machine from beginning to end. Down to 2307 feet the fish-tail bit, the core-barrel bit, the square bit, and the diamond-shaped bit were used; the two latter were used only when very hard ground was encountered, or when some obstruction had to

be worn away. Below 2307 feet the roller bit was used, being found much superior, when in order, to other bits for drilling in limestone or other moderately hard rock. Coring was done for the following depths (in feet below surface): 913.5-963, 969-1033, 1035-1053, 1055-1068, 1082-1143, 1151-1169, 1225-1250, 1253-1270, 1273-1280, 1284-1287, 1288-1309, 1313-1320, 1331-1331.5, 1369-1370, 1494-1510, 1525-1558, 1566-1627, 1705-1713, 1806-1810, 1827-1830, 1838-1845, 2244-2255, 2256-2264.

The deepest run for a day with the fish-tail bit was 57 feet, at the depth of from 225 to 282 feet; the next three highest runs were 56 feet, from 121 to 187 feet; 38 feet, from 187 to 225 feet; and 36 feet, from 2071 to 2107 feet. These speeds were in soft red sandstones and shales, containing some small beds of gypsum. The slowest drilling was in strata containing flint and other concretionary quartz, where the speed was reduced to from six inches to a foot for a day's continuous work. From Mr. Minihan's notes it appears that the average depths drilled in a day of eight hours, by different drills, was about as below, for the different rocks explored:

Average Rate of Drilling in Different Rocks and by Different Drills, in Feet per Day

	Soft sandstone and sandy clay	Shale	Limestone	Hard sandstone	Flint beds
Roller bit		18	10	5	2
Fish-tail bit	20	20	5	3	1

STUDY OF ROCK SAMPLES

To properly interpret the driller's section, some 330 samples of drillings and pieces of core have been examined. Thin sections were made of some 200 rock samples, nearly all dolomite, limestone and anhydrite, and notes were taken on a number of minute fossils found in the cuttings of limestone and shale mostly in the lower 2400 feet of the well.

Taking of the Samples

The number of rock samples which have been examined is 330. The first fifty-eight of these were cuttings selected by the driller to represent the several strata explored in the first 914 feet. From this depth down to 1174 feet, the samples are mostly broken pieces of core similarly selected. From 1174 to 1250 feet no more than two samples of cuttings represent the ground penetrated. From 1250 to 2042 feet there were only five samples taken from depths definitely known, but there are four more samples known to have come from somewhere between these two depths. All are pieces from cores. From 2042 to 3050 feet the section is represented by 48 samples, some of which are selected to represent the formations, and some not thus selected. From 3050 feet down to the bottom came 202 samples, which are cuttings taken quite regularly every five or ten feet, irrespective of the nature of the rock drilled.

Mixing of Returns in Rotary Drilling

It is sometimes urged that the identification of strata explored by examination of cuttings in rotary drilling is impossible, on account of the mixing of the returns. This is not at all the case. In the first place, no rock can appear in the returns before it has been entered. There is no possibility of the mixing in of any accidental foreign ingredient except from above. Examining the samples in the order from above downward, the upper formations are known and are usually easily recognized. When mud is prepared and used to support the walls in case of soft ground, the case is different, of course. Mixing of returns increases with depth and an extreme case can be gauged in the lower part of this well after it was cased down to 3044 feet. The finest material silts out very tardily in the mud pool, and may remain in circulation no doubt for several days. But the old fine mud is continually diluted and replaced by new fine material. The coarser material consisting of particles a half millimeter or more in diameter

settles in the reservoir more promptly, and at the average rate of drilling it practically disappears from the cuttings in from ten to thirty or forty feet, even at a depth of 4000 feet. Thus it will be seen that brown limestone reported at from 3964 to 3975 feet disappeared from the drillings below the depth of 3990 feet. The white limestone which first appeared in the drillings at 4095 feet had mostly disappeared at 4145 feet. In this latter case, it is possible that the transition from dolomite to limestone was itself gradual, or intermittent. From 4152 to 4163 the driller reports very hard limestone, and it is evident that the slow drilling at this depth was due to chert, which appears in the drillings promptly from 4150 to 4155 feet and continues in the sample taken at 4160 to 4165 feet. The more slow the drilling, the purer is the sample. Fine sand consisting of grains more or less rounded is apt to stay with the silt in circulation. The driller reports in this boring a red sand rock at 2541 to 2551 feet, and again at 2640 to 2653 feet. Some red sand grains are present in most of the material from between these depths. Shaly admixtures show greater irregularity, owing no doubt to caving. But this affects the samples taken from other than rotary drilling as well. In the case of a shale reported at from 3060 to 3075 feet in the present instance, an increase in the shale in the returns began at 3070 feet and there was a noticeable diminution at 3080 feet. The essential reliability of the samples in the present case is evident from a comparison of the section as made out from the cuttings with the speed of the drilling. Wherever chert, or flint, appears in the cuttings, drilling was slow; while, in case where shale and some sandstone appears in the returns, the work was most rapid. (See Plate 13.)

Descriptions of Samples

Descriptions of the samples have been made as full as possible in the hope that when we shall have a more detailed knowledge of these formations from their outcrops, it may be possible to make correlations with greater confidence and precision than is possible at the present time.

		Feet From.	Feet To.
1.	Soil	0	2
2.	Sub soil	2	6
3.	Pinkish yellow sand	6	16
4.	Gravel	16	23
5.	Brown sand	23	27
6.	Bright red marl	27	53
7.	Red marl and gravel	53	65
8.	Gypsum and red clay	65	75
9.	Red sandy shale, crystalline and fibrous gypsum, some limestone, fragments of quartz and chert pebbles. The shale shows some light blue spots	75	85
10.	Red clay and red sand of fine texture	85	98
11.	Gypsum	98	101
12.	Gypsum	101	108
13.	Red sandy shale	108	115
14.	Gypsum	115	119
15.	Red sandy shale	119	135
16.	Brown sandy shale, blue shale, and much gypsum	135	137
17.	Red sandy shale. Some shale shows blue circular spots ⅛ mm. in diameter	137	149
18.	Red sandy shale and gypsum	149	153
19.	Red sandy shale and gypsum	153	192
20.	Gypsum	192	199
21.	Red marl	199	221
22.	Crystalline gypsum, structureless gypsum, and some red shale	221	223
23.	Red marly clay or shale, most particles measuring from 0.001 to 0.04 mm. in diameter	223	239
24.	Crystalline gypsum	239	254
25.	Soft red sand of fine texture, with some calcareous material	254	272
26.	Bright red clay, calcareous	272	285
27.	Compact anhydrite and some white gypsum, and red shale	285	298
28.	Deep red sand of fine texture	298	330
29.	White, compact, or finely granular anhydrite	330	403
30.	Gravelly and well-worn sand, red limestone, and sandy shale, with gray chert. This sample contains some small crystals of anhydrite, some lumps of anhydrite and a few scales of gypsum	403	468
31.	Red sand of fine texture	468	532
32.	Sand, clay, and anhydrite	532	538

		Feet From.	Feet To.
33.	Red and gray sand, with white fine-grained and tough and hard anhydrite and red granular limestone	538	540
34.	White tough anhydrite	540	568
35.	White, tough and close-grained anhydrite	568	570
36.	Salt, finely granular, mixed with (1-20) fine red sand and silt, and showing laminations of the thickness one-half to two mm	570	580
37.	Worn quartz sand from 1 to ¼ mm. in diameter, and some anhydrite in entire granular crystals	580	586
38.	Anhydrite of fine granular texture, pink, red, and white, with some red sandstone having white blotches	586	596
39.	Mostly quartz sand. Also red silt and clay. Calcareous fragments, black, white and red	596	603
40.	Tough, compact, white anhydrite	603	624
41.	White anhydrite, some finely granular, some more compact in texture	624	628
42.	Red sand and silt, with much calcareous materials. Crystals of anhydrite and quartz noted	628	633
43.	No sample. Driller reported salt	633	638
44.	Silty red sand with light gray spots and blotches, and containing small particles of anhydrite, calcareous	638	645
45.	Red sand and clay with some calcareous material	645	674
46.	Quartz sand, coarser and clearer than the average in preceding samples	674	688
47.	Red sand of fine texture, with red silt	688	715
48.	Red sand of fine grains	715	725
49.	Anhydrite, compact, bluish white	725	732
50.	Salt. transparent and crystalline, but clouded with blotches of red silty material	732	741
51.	Dark red silty sand, and some coarse sand with some compact anhydrite. Crystals of quartz, anhydrite and gypsum noted	741	773
52.	Anhydrite, showing cracks and joints, mostly white, some pink	773	778
53.	Red sand of fine texture. Crystals of anhydrite and quartz noted	778	804
54.	Dark red sand, shale and clay, with thin foliations of gray anhydrite	804	812

		Feet From.	Feet To.
55.	White, irregularly finely laminated anhydrite. A sample from this depth was ground to powder, very fine, by the bit. This powder stuck to bit, and dried (set) to a hard cake, almost pure white. This was sulphate of lime, mostly gypsum, containing much water	812	816
56.	Red sand of moderately fine texture	816	853
57.	White anhydrite of fine texture	853	858
58.	Red sand, with some clayey material	858	914
59.	Red, fine-grained sandstone, with gray spots, and containing 20 per cent salt (no potash) and a red rock consisting of 67 per cent of salt and 33 per cent sand. The salt is crystalline, showing large crystalline surfaces with continuous reflections. The salt and sand are very evenly mixed	914	931
63.	A dark brown rock consisting of 68 per cent silt (none of silt above ⅛ mm. in diameter of grains) and 40 per cent of salt. The silt has the fineness of loess. Rock is laminated	931	932
61.	Gray compact anhydrite, in a separate sample from		931
62.	Crystalline salt and fine red sand	950	1000
63.	A dark brown rock consisting of 69 per cent of silt, and 32 per cent of salt. No potash. The silt is of about the fineness of loess. Continuous reflections of the crystalline salt were noted	958	962
64.	Granular anhydrite, with grains about ⅛ mm. in diameter. This contains scattered subangular grains of quartz, about ⅓ mm. in diameter, and some grains of a green mineral, in a separate sample from		992
65.	A brownish red rock consisting of 50 per cent of red sand and 50 per cent of salt. Test for potash negative	962	1113
66.	Gray, close-grained anhydrite, containing some salt, was noted in a sample from		1005
67.	A laminated, close-grained, gray and grayish pink anhydrite, containing from 5 to 8 per cent of salt, no potash, and some siliceous silt. It contains no limestone. Some grains of a green mineral were noted	1113	1117

	Feet From.	To.
68. A blotchy brown and gray close-grained rock showing reflections of halite. It contains 37 per cent of salt. No potash. The rest is sand and silt	1117	1123
69. A close-grained bluish gray anhydrite, quite free from impurities. No reaction for limestone	1123	1125
70. A red, sandy and silty rock, showing mica scales in some seams and reflections of halite on some fractures vertical to the indistinct lamination. It contains 30 per cent of salt, and the insoluble material is in part siliceous sand and silt, and contains some anhydrite	1125	1174
71. Fine sand and silt and some calcareous fragments, black, white, and red, evidently from concretions. Some anhydrite. The rock loses about 15 per cent by solution in cold water. The rock also contains some coarse quartz sand, well rounded. Some chert noted. No potash	1174	1222
72. Brown sandy silt, with some larger fragments of limestone or calcerous concretions. Some anhydrite. No potash	1222	1235
73. Mostly white and gray anhydrite, mixed with a few calcareous fragments and much red sand and silt. Crystals of anhydrite and gypsum noted	1235	1250
74. From between 1250 and 2042 feet below the surface came several pieces of cores, from depths not specified, as follows: (1) A part of a large septarian concretion. It shows two fissures at right angles filled with anhydrite, calcite and pyrite. The matrix between these fissures consists of a dark gray, very compact material, effervescing slowly in acid, but not slacking in water after exposed to reducing flame, nor becoming magnetic. (2) Two pieces consist of dark gray, impure limestone, stratified. One is obscurely oolitic, the other is an oolitic fine-textured organic breccia, in which an apex of a gastropod, some bryozoans, and foraminifera were noted. (3) A siliceous dolomite, dark gray, effervescing slowly, thinly laminated, laminae about 89 in one inch.		

	Feet	
	From.	To.
Seen in vertical section, the laminae are irregular, turning in small abrupt bends so as to frequently diverge, converge and end at irregular intervals. In places, they turn around small imbedded granules. The laminae are marked by black, very thin folia, which are separated by thicker layers of transparent material. The rock gives fumes of bitumens and sulphur when heated in a closed tube. Plate 1, B. (4) A dark gray dolomite of fine texture. In thin section it is seen to consist of fine oolitic material,		

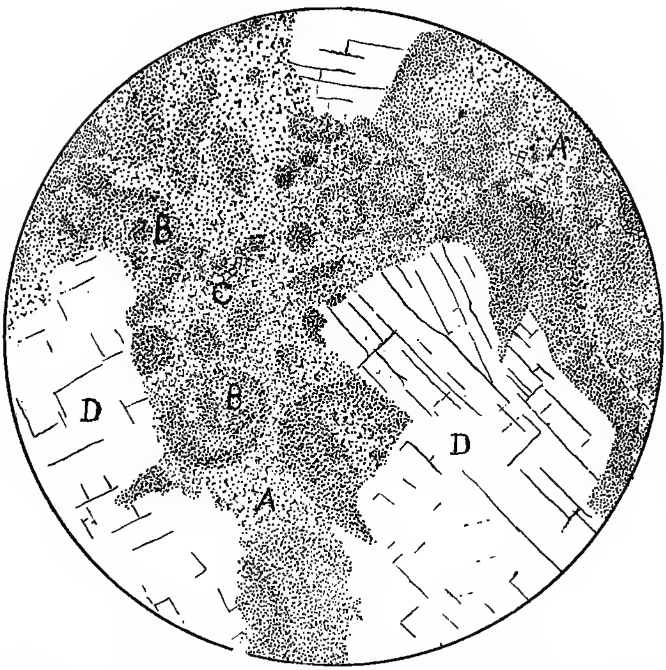

FIGURE 1. Impure oolitic and concretionary dolomite. From between 1250 to 2042 feet below surface. Part of the rock is replaced by anhydrite. A.A. Matrix of the concretionary rock, showing crystals of dolomite 0.01 mm. in diameter. B.B. Minute concretions imbedded in the matrix and having a fine texture. C. Trace of a fossil in the original rock, shown by a smoothly curving zone of crystals of larger size than the prevailing crystals in the matrix. D. D. Crystals of anhydrite replacing part of the matrix and parts of concretions. Magnified about 50 diameters.

	Feet From.	To.
the spherules being slightly less than 1 mm. in diameter, oval and spherical. With these are mingled many organic fragments. Some of these are thin fragments of ostracod shells, minute fragments of bryozoa and foraminifera, apices of gastropods, and tubular structures. One of the foraminifera has biserially arranged chambers. In one section a perforate test was noted. Plate 1, A	1250	2042
75. Gray, close-grained anhydrite, at		1590
76. A dark gray dolomite limestone with cherty layers. There are alternate layers of darker and lighter gray, the darker being the more siliceous. In thin section the rock is seen to		

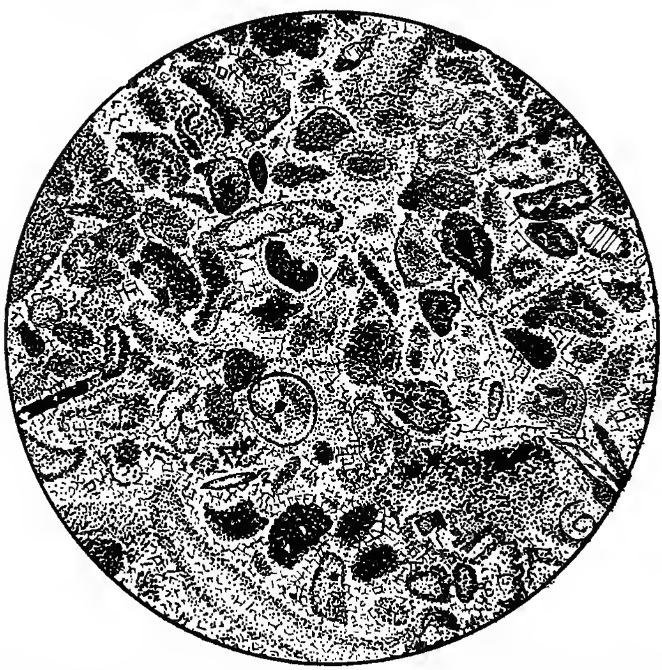

FIGURE 2. Section of rock somewhere from 1250 to 2042 feet below the surface. Dolomitic oolite containing imbedded shells of ostracods, gastropods, foraminifera. Slight impregnations of bituminous material give a brown tinge to many of the spherules and organic fragments. The matrix in which the spherules are imbedded is more coarsely crystalline than the spherules themselves. See Descriptions of Samples 74 (4). X about 30.

	Feet From.	To.
consist of a matrix of minute dolomite crystals. Among these there are larger obscurely outlined, elongated bodies which are siliceous. Some of them have a faint resemblance to sponge spicules, being straight. The others are more like small fragments of thin shells, broken so as to be about twice as long as thick. Along some planes in the rock are small cavities filled with chalcedonic quartz. These cavities are mostly spherical and from less than ½ to 1 mm. in diameter. The chalcedony shows imbedded rectangular bodies which have a tendency to lie end to end, in irregular chains. The rock shows minute black streaky stains, probably manganese. This sample is doubtfully labeled as coming from		1600

FIGURE. 3. Vertical section of siliceous dolomite from somewhere between 1250 and 2042. See Descriptions of Samples, 74 (3). X about 40.

	Feet From.	To.
77. Gray magnesian limestone of fine texture. It is porous and when ground dry has a slight bituminous odor. In thin section it is seen to be a finely crystalline dolomite, filled with porosities, angular or spherical. As there was much salt on the surface of the specimen, it seems likely that these porosities had contained the salt. Plate 2. From		1600
78. A section from rock at 1800 feet consists of an oolite matrix, dolomitized, in which are included crystals of anhydrite, which constitute one-half of the mass, nearly, and have replaced the oolitic matrix. This closely resembles the other oolitic rock, from 1250-2042 feet, described above. Plate 3		1800
79. A dolomitic limestone of fine texture, containing spherical pockets of anhydrite in small crystals of irregular arrangement. The crystalline texture in the dolomite exhibits a grouping which indicates clastic or oolitic structure in the original rock. Black streaks and particles of marl, apparently, are numerous. Imbedded straight sponge spicules are also seen in places, in the arrangement of the crystals of the dolomite	1810	1870
80. Blue shale, effervescing slowly in acid. There are some white fragments which consist of a tangle of slat-like crystals. This rock gives a trace of potash	2042	2047
81. Fine sand, red, mixed with gray shale and anhydrite. At red heat the shale gives very strong fumes of sulphur	2047	2049
82. Soft, shaly limestone, dove-colored	2049	2063
83. Gray, purple and red anhydrite with some brown shale and a few grains of red and white limestone	2064	2068
84. Deep brown, highly ferruginous and slightly micaceous, sandy shale, and dark gray, soft anhydrite-bearing dolomite. Sample gives a trace of potash	2068	2110
85. Soft gray dolomite, and some gray shale	2110	2127
86. Dark red clay, containing some fine mica and very fine sand	2128	2212

No.	Description	Feet From.	Feet To.
87.	A thinly, curvingly laminated gray dolomite with red sandy shale, and anhydrite. Also gray shaly dolomite	2212	2214
88.	Gray dolomite and some almost black and greenish gray calcareous shale, with a few large and rounded quartz sand grains. Some white quartz present. Some white calcareous grains and some brown shale. The black shale contains small angular crystalline particles of anhydrite, gives fumes of oil and sulphur in closed tube	2214	2219
89.	Gray dolomite. No flint noted. Much anhydrite and some red silt	2219	2241
90.	A light gray dolomite of fine texture, very soft. In thin section it is seen to consist of uniformly small crystals of dolomite. There are some very thin black lines, probably bituminous. These follow the bedding planes in broken irregular curves. The core contains a concretion of anhydrite, some three inches in diameter, imbedded in the rock. This concretion partly is lined externally by a layer of white quartz and it also contains nodules of quartz internally. The rock yields fumes of bitumen, sulphur and ammonia when heated in closed tube. Plate 4, A		2250
91.	Five fragments of rock weighing from 5 to 10 grams each. One is a laminated gray dolomite of fine texture. Two fragments are gray chert. One is apparently from septaria, showing vein material of gypsum and pyrite one-fifth of an inch thick, on two surfaces at oblique angles to each other. One fragment consists of anhydrite, showing black cloudy specks	2241	2271
92.	A dark gray impure dolomite, soft, and breaking like shale; shows fine but obscure lamination and shows grouping of crystals indicating original organic fragmentary structure. Several concretions of chalcedonic quartz noted, from one-fourth to one inch in diameter. This rock contains some salt	2244	2264

	Feet From.	To.
93. A gray fossiliferous oolitic dolomite. A small lamellibranch, a spiral shell of small size, and a bryozoan were noted; under hand lens some small bryozoa were noted and the entire rock was seen to consist of a matrix in which there are imbedded round and oval bodies of variable shape, like oolitic spherules. Nearly all of these show an outer limiting crust. Most of them are from one-sixth to one-half mm. in diameter. Some are several times as long as broad, and one showed a row of internal chambers. Some are clearly foraminifera. Heated in closed tube, bituminous fumes are produced. Plate 5	2250	2264
94. A light gray dolomite of fine texture, and soft. It contains concretionary structures of lighter gray. In thin section many brownish dark streaks of bituminous matter are seen and scattered small pockets of anhydrite. In a concretion some light specks and straight crystals are seen. These are probably quartz. In closed tube it distils oil and gas. Taken at		2260
95. Oolitic dolomite, containing much secondary anhydrite. Plates 6 and 7		2264
96. Gray dolomitic shale and shaly limestone, containing fragments showing a tangle of slat-like crystals like those at 2042-2047 feet below surface. Obscure fragments of shells. A thin horizontal section shows some small circular areas of more compact dolomitic material	2271	2329
97. Like the preceding, but with more anhydrite and gypsum	2329	2331
98. White granular anhydrite and gray anhydrite	2331	2336
99. Brown, gray and white granular anhydrite. No sand noted	2336	2338
100. Mainly white granular anhydrite with some light gray dolomite. In thin section this dolomite is seen to consist of crystals less than 0.01 mm. in diameter, among which are scattered crystalline bodies of anhydrite of larger size	2338	2392

		Feet From.	To.
101.	Black shale, some red sandy and micaceous silt, some gray shaly dolomite. The black shale emits bituminous and sulphurous fumes when heated in a closed tube	2392	2394
102.	White and gray anhydrite, mostly. A fragment of anhydrite contains streaks of finely granular dolomite and a fragment of dolomite contains angular particles of anhydrite	2394	2454
103.	Mostly white granular anhydrite. A part of the sample is a red silt, slightly calcareous. A few quartz grains were noted, small, angular and rusty	2454	2460
104.	Gray dolomite containing scattered grains of anhydrite and cavities from which the anhydrite has been dissolved, probably. Some red silt and quartz grains noted	2460	2476
105.	White and gray anhydrite and some greenish shaly limestone and shale, dolomitic	2476	2539
106.	Mainly anhydrite. A dolomitic oolite in which the texture is obscured by the process of dolomitization and by a partial replacement of the dolomite by anhydrite. Much anhydrite and a few grains of rusty quartz sand present	2539	2545
106a.	Mostly white anhydrite and some gray dolomite	2545	2606
107.	Gray, soft dolomite and much anhydrite. In thin section the limestone is seen to be an oolite, containing much anhydrite. Some red shale and rusty quartz grains present	2606	2609
108.	Gray dolomite, consisting of oolitic oval spherules. Both matrix and spherules contain nearly one-half their bulk of introduced anhydrite. The spherules have sharply defined outlines and measure 0.2 mm. in diameter	2609	2624
109.	Gray, soft dolomite and anhydrite, with some red sand grains	2624	2644
110.	Red clay, red quartz sand, and some limestone	2644	2660
111.	White anhydrite, with a few fragments of gray, soft dolomite	2660	2664
112.	Red clay and silt and brown and gray anhydrite, and quartz sand	2664	2673

		Feet	
		From.	To.
113.	Light bluish gray and soft dolomite containing much introduced anhydrite. Some red clay and sand. One fragment shows clusters of spicular structures, probably from sponges. Plate 9, A	2673	2677
114.	A rock which consists of variable ratios of gray dolomite and anhydrite, with some red sand, some shale, and some red anhydrite. The outlines of a chain of chambers of a Nodosaria (?), composed of dolomite crystals are preserved in a matrix of anhydrite in one fragment	2677	2682
115.	Gray and blotched white anhydrite in slender crystals of roughly fascicled arrangement	2682	2685
116.	Red shale and gray dolomitic limestone. Some of the latter is of uniformly fine texture, some contains many imbedded crystals of anhydrite. Some dolomite shows traces of oolitic structure. Bituminous matter present in streaks in the rock	2685	2698
117.	Yellowish gray, bituminous dolomitic limestone, containing many clear crystals of anhydrite and yellow streaks of bituminous matter. Distils oil in closed tube and also ammonia	2698	2709
118.	Light and dark, gray dolomite. The dark fragments effervesce most slowly. In some of the dark fragments is clear anhydrite, filling oolitic spherules and foraminifer tests. Some red shale. Plate 9, B	2709	2735
119.	Dolomitic limestone and fine yellow quartz sand, mostly from 0.25 mm. to 0.06 mm. in diameter. The grains have a thin coating of red oxide of iron and are not thoroughly rounded. No foraminifera seen in the limestone, but traces of other organic forms noted. Gypsum, pyrite, and anhydrite seen	2735	2751
120.	Dark gray and light yellow oolitic dolomite, some coarse and rounded quartz sand, and some red shale. Some of the limestone contains clear anhydrite in a matrix of uniformly fine crystalline dolomite. Pyrite noted, and gypsum	2751	2900
121.	Gray dolomite. Under the microscope it is seen to be traversed by anhydrite. Some light colored fragments consist of minute round		

		Feet	
		From.	To.
	lumps of a micro-crystalline dolomite included in a copious matrix of anhydrite. One fragment is clearly an oolite, with a matrix of anhydrite. Others are altered oolitic dolomite with spherules less well preserved	2900	2950
122.	Like the preceding, with obscure traces of fossils	2950	2956
123.	Rock like the preceding. No traces of fossils noted. Minute gypsum crystals noted	2956	2980
124.	White anhydrite	2980	2995
125.	A bluish gray dolomite with black minute streaks, with small pockets and concretions of anhydrite. In thin section the body of the rock is seen to consist of small crystals of dolomite among which are brown streaks, and some angular and other cavities filled with anhydrite. Some faint curving marks resemble traces of fossils	2987	3002
125a.	Yellow oolitic limestone and yellow dolomite of compact texture, showing oolitic spherules and thin imbedded fragments, probably organic. There is some gray sandy shale and some anhydrite. Some dolomite contains anhydrite, replacing a part of the original rock	2995	3050
126.	Anhydrite and gray dolomite. The dolomite consists of crystals of uniform size, about 0.008 mm. in diameter. It contains black and rusty red specks and streaks. The specks are much smaller than the crystals	3044	3046
127.	Dark greenish gray shale, and some yellowish gray dolomitic limestone	3046	3050
128.	Gray oolitic dolomite. Some spherules have the outlines of organic fragments. Introduced anhydrite present	3050	3055
129.	Yellowish gray dolomite, somewhat compact in texture	3055	3058
130.	Yellowish gray dolomite and greenish shale	3058	3060
131.	Dark shale, of conchoidal fracture and fine homogeneous texture, slightly calcareous. With this is a concretion of anhydrite of an oblate spheroid shape, nearly an inch in diameter	3060	3065
132.	Dark shale and some yellow dolomite	3065	3070
133.	Greenish dark shale, with some fragments of yellow dolomite	3070	3075

		Feet From.	To.
134.	Dark shale, yellow dolomite, anhydrite and gypsum	3075	3080
135.	Dark shale and anhydrite, with fragments of yellowish gray dolomite	3080	3085
136.	Greenish gray shale, dark shale, and anhydrite	3085	3090
137.	Green shale, dark shale, some yellowish gray dolomitic rock, effervescing somewhat rapidly for a dolomite. The green shale has minute dark curving streaks	3090	3095
138.	Dark shale, a compact yellowish gray dolomite, and anhydrite	3095	3100
139.	Dolomite, anhydrite and shale	3100	3105
140.	Anhydrite and dark green shale, with some dolomite	3105	3110
141.	Dark green shale, with some yellow dolomite and some anhydrite	3110	3115
142.	Yellowish dark gray dolomite of marked oolitic texture and with a matrix containing introduced anhydrite. Much dark green calcareous shale	3115	3120
143.	Shale and dolomite	3120	3125
144.	Like the preceding	3125	3130
145.	Dark greenish gray shale and compact yellow dolomite with some anhydrite	3130	3135
146.	Like the preceding	3135	3140
147.	Mostly dark shale and some brownish gray dolomite. The dolomite has secondary anhydrite and shows traces of brecciated and oolitic texture in some fragments	3140	3145
148.	Dolomite and shale. Dolomite has imbedded dark fragments, in part angular	3150	3155
149.	Dolomite and dark shale. Dolomite effervesces slowly, is mostly yellowish gray, and minutely brecciated in some fragments. It contains some secondary anhydrite	3155	3160
150.	Mainly yellowish gray limestone, some of which is calcareous. Also some dark shale	3160	3165
151.	Dark and light gray dolomite of uniform and compact texture and with secondary anhydrite. In closed tube it distils oil	3165	3170
152.	Like the preceding	3170	3175
153.	Shale and yellowish gray dolomite. Some sand in a white calcareous matrix	3175	3180
154.	Gray dolomite, with inclosed dark particles	3180	3185

		Feet From.	To.
155.	Dark gray dolomite with much secondary anhydrite. An organic fragmental structure is indicated by the filled mould of a shell fragment in one case and by the grouping of the dolomite crystals. Streaks of brown bituminous material present. Distils oil in closed tube	3185	3190
156.	Like the preceding	3190	3195
157.	Like the preceding	3195	3200
158.	Whitish dolomite, with imbedded minute darker fragments. Considerable anhydrite, green and dark shale. Pyrite in shale	3200	3205
159.	Some dolomite containing secondary anhydrite, some oolitic dolomite with streaks of bituminous material, and with structure showing traces of shell fragments, and some dark shale. A fragment of anhydrite contains many octahedrons of pyrite less than 0.02 in diameter	3205	3210
160.	Dolomite of fine texture, containing small grains of a transparent mineral, probably anhydrite, evidently of secondary origin. Anhydrite fragments contains minute cubes of an opaque mineral	3210	3215
161.	Dolomite and much dark green shale	3215	3220
162.	Dark dolomite with some imbedded fragments of different shade. Bluish green shale	3220	3225
163.	Some white rock, effervescing somewhat readily for dolomite. Also dark dolomite and green and dark shale	3225	3230
164.	Dark green and dark gray shale and dolomite. The dolomite shows traces of oolitic spherules in some fragments and traces of irregular fissures	3230	3235
165.	Mostly dark green and black shale, with limestone as above	3235	3240
166.	Like the preceding, with some anhydrite	3240	3245
167.	Like the preceding, but with less anhydrite and more light gray dolomite. This dolomite has imbedded small lenticular bodies of darker dolomite, and is traversed by irregular bodies of anhydrite. Plate 10, A	3245	3250
168.	Light gray dolomite, dark brown limestone, and much dark green shale	3250	3255

		Feet From.	To.
169.	Dark dolomite, and dark shale	3255	3260
170.	Like the preceding	3260	3265
171.	Very dark dolomite, with black and green shale	3265	3270
172.	Dolomite, thinly laminated, of some very dark and some almost white layers. Much shale	3270	3275
173.	Green and dark shale with dark and white dolomite	3280	3285
174.	Shale and dark dolomite showing, in the grouping of the crystals, obscure traces of clastic structure. Streaks of bituminous matter present. Distils oil in closed tube	3285	3290
175.	Like the preceding	3290	3295
176.	Like the preceding, with some shaly gray limestone	3295	3300
177.	Green shale and yellowish gray dolomitic limestone. The limestone contains minute cavities of irregular form filled with anhydrite. The dolomite crystals vary in size in spots, indicating original clastic structure, and fragments of organic forms	3305	3310
178.	Like the preceding	3310	3315
179.	Light gray dolomite of fine texture, like shale in appearance	3315	3320
180.	Dolomite and greenish black shale	3320	3325
181.	Dark green and dark gray shale	3325	3330
182.	Dark greenish blue shale, and some dolomite. The dolomite is of coarse texture, crystals measuring 0.02 to 0.03 mm. in diameter. Some sharply limited "islands" of dolomite of fine texture occur in that of coarse texture. Plate 10, B	3330	3335
183.	Dark and greenish blue shale, gray and yellow dolomite. There is also some white anhydrite. Some microscopic tubular (?) jointed fragments noted	3335	3340
184.	Like the preceding	3340	3345
185.	Mostly yellowish dolomite. Some white limestone, some dark shale	3345	3350
186.	Some yellow dolomite, porous. In some fragments, black streaky layers were noted, both in this and the preceding sample. Greenish and dark shale. A grain of pyrite noted	3350	3355
187.	Dark gray dolomite containing secondary anhydrite and yielding oil when heated in closed tube	3355	3360

		Feet From.	To.
188.	Greenish gray shale and some almost black shaly, dark gray dolomite, and a few fragments of calcareous material	3360	3365
189.	Mostly greenish gray shale, and dark gray shale	3365	3370
190.	Dark gray shale, dark and light gray dolomite and some greenish gray shale	3370	3375
191.	Dark gray and greenish gray shale, and gray dolomite	3375	3380
192.	Like the preceding, but with less shale	3380	3385
193.	Gray and dark gray dolomite, and dark gray and some greenish gray shale. The texture of the dolomite is coarse, the crystals measuring from 0.02 to 0.03 mm. in diameter. Some secondary anhydrite present	3385	3390
194.	Light gray and dark gray dolomite and dark gray and greenish gray shale	3390	3395
194a.	Light gray and straw colored dolomite and some greenish gray shale	3395	3400
195.	Dolomite and shale. Some of the dolomite has coarse, some fine texture. The coarse has much secondary anhydrite. The fine-textured dolomite shows a grouping of the crystals into clusters of uniform size, 0.04 to 0.05 mm. in diameter. Plate 11, A	3400	3405
196.	Like the preceding	3405	3410
197.	Yellowish dolomite, gray dolomite, green hard shale and some gray shale	3410	3415
198.	Yellowish dolomite, light gray and dark gray dolomite, and a small amount of limestone. Green shale and a small amount of gray and black shale. A small amount of anhydrite	3415	3420
199.	Light and dark gray and yellowish dolomite. Some limestone. About one-third blue, dark, and green shale. Some anhydrite	3420	3425
200.	Gray and yellowish dolomitic limestone, greenish gray and black shale. Anhydrite is present, mainly in the fine material A very little limestone is present	3425	3430
201.	Gray and yellow dolomite, dark limestone, green shale and some anhydrite, the latter mostly ground to very fine material. A very little limestone is present	3425	3430
202.	Dark and yellow dolomite, some green shale. Anhydrite fragments were large in size in this sample	3435	3440

		Feet From.	To.
203.	Gray and yellowish dolomite, green and black shale becoming less. Anhydrite present in the finer sizes of the sample	3440	3445
204.	Gray, yellowish gray, and dark gray dolomite, and bluish green shale with some dark gray shale	3445	3450
205.	Dolomite containing secondary anhydrite and shale of dark gray and green color. Some of the green shale shows dark streaks	3450	3455
206.	Gray, dark gray and yellowish dolomite, and some dark gray and bluish green shale	3455	3460
207.	Like the preceding	3460	3465
208.	Like the preceding. Dark shale slightly more abundant	3465	3470
209.	Mostly gray dolomite, some dark gray dolomite, some yellow dolomite, some fragments of almost black dolomite and only a little shale	3470	3475
210.	Gray, white, yellow and dark gray dolomite, and greenish blue and gray shale	3475	3480
211.	Gray, yellow and very light or white dolomite, and green and gray shale. A few calcareous fragments noted	3480	3485
212.	Like the preceding. Some of the gray dolomite was seen to have dark gray blotches	3485	3490
213.	Dolomite and shale. The dolomite contains some secondary anhydrite and shows traces of clustered tubular structures, 0.15 mm. in diameter. Plate 12, B	3490	3495
214.	Like the preceding, in part. Some dolomite has crystals arranged in clusters	3495	3500
215.	Gray, light gray or white, and yellow dolomite. The white and yellow dolomite is very compact. Dark gray and blue shale. The blue shale has minute microscopic dots, black	3500	3505
216.	Like the preceding. Some more calcareous fragments	3505	3510
217.	Like the preceding	3510	3515
218.	Yellowish dolomite of very fine texture, crystals measuring less than 0.01 mm. Pockets of anhydrite occur and anhydrite fills some narrow crescentic or half-annular spaces, believed to be moulds of fossils. The mass of the rock shows distinct traces, in the grouping of the crystals, of clastic structure	3515	3520

		Feet From.	To.
219.	Like the preceding	3520	3525
220.	Dark gray blotchy dolomite, dark gray shale quite abundant. Some blue shale and white compact dolomite. Effervesence somewhat brisk for dolomite	3525	3530
221.	Shale and dolomite in about equal quantities. Some shale is black	3530	3535
222.	Much dark, black and green shale, interlaminated in one fragment. Gray and yellow dolomite. Several calcareous fragments. Shreds of vegetation noted in one fragment of black shale	3535	3540
223.	Mostly green and dark gray dolomite. Some shale, blue and dark	3540	3545
224.	Dolomite and shale. The dolomite contains some secondary anhydrite. In the arrangement of its crystals a thin section of the dolomite shows obscure traces of tubular structures, 0.03 mm. in diameter, and also traces of small shells, probably ostracods. Plate 11, C	3545	3550
225.	Mostly gray and yellow dolomite, some shale. One fragment of blue shale was seen to be very finely laminated with white. Pyrite noted in gray dolomite	3550	3555
226.	Dolomite and almost as much shale. Some dark shale has imbedded bituminous shreds of vegetation, brown, translucent. One oblong spore-like body noted	3555	3560
227.	Blue and yellow shale and dolomite in about equal quantities. Considerable black shale	3560	3565
228.	Like the preceding	3565	3570
229.	Mostly dolomite and shale of same appearance as in preceding sample	3570	3575
230.	Dark gray dolomite, lighter dolomite and yellow dolomite. One fragment of shale was blue with shreds of black material imbedded. No sand noted	3580	3585
231.	Like the preceding, but with more dark shale, and some calcareous material	3585	3590
232.	Dolomite and shale. Shreds of vegetation noted in some of the dark shale. Pyrite noted in the dolomite	3595	3600
233.	Bituminous dolomite, mostly gray. Dark and green shale	3600	3605

		Feet From.	To.
234.	Dark dolomite and shale in about equal quantities. Shreds of vegetation noted in dark shale. Some green shale noted. No sand seen. Yields oil in closed tube, and yields ammonia. Bituminous matter in irregular streaks and particles among crystals	3605	3610
235.	Like the preceding. White dolomite absent, was present in the last preceding samples	3610	3615
236.	Mostly gray minutely blotched dolomite, and dark gray shale, seen to be sometimes finely laminated	3615	3620
237.	Dark gray shale, gray dolomite, some green shale	3620	3625
238.	Dark gray minutely blotched dolomite, and dark gray shale. Some calcareous fragments present	3625	3630
239.	Dolomite and shale. In the shale some minute flakes of mica were noted. In the dolomite are some straight and gently bending tubular structures about 0.03 mm. in diameter. Some anhydrite present in the limestone	3630	3635
240.	Dark dolomite and shale. Mica noted in shale. Calcareous fragments present, but scarce	3635	3640
241.	Minutely blotched dolomite and dark gray shale. Calcareous fragments very few	3640	3645
242.	Dark dolomite and dark shale. Calcareous material wholly absent. In thin section, obscure traces of clastic or concretionary, and of organic structures were noted. Anhydrite present in small crevices, which are not well defined	3645	3650
243.	Like the preceding. The dark dolomite was seen to have black streaks and imbedded black, minute lumps or grains. No sand present. Yields sulphur fumes	3650	3655
244.	Like the preceding with some coarse fragments of anhydrite	3655	3660
245.	Like the preceding	3660	3665
246.	Like the preceding	3665	3670
247.	Dark and blue shale and dolomite	3670	3675
248.	Dolomite and shale. In the dolomite is much secondary anhydrite which in its distribution has left obscure traces of oolitic or clastic textures	3675	3680

		Feet From.	To.
249.	Like the preceding. Both the dolomite and dark shale give off bituminous fumes in closed tube	3680	3685
250.	Gray dolomite and dark gray shale	3685	3690
251.	Like the preceding. The dark dolomite is strongly bituminous in closed tube	3690	3695
252.	Dark gray, minutely blotchy, bituminous dolomite and dark shale. The dolomite has imbedded black grains. In closed tube gives trace of oil and fumes of gas	3695	3700
253.	Dark gray and yellow dolomite and dark shale. There is also some white anhydrite. The dark dolomite gives oil and strong bituminous odors in closed tube. In thin sections, dark bituminous streaks are seen and the crystals are grouped in forms indicating organic fragments	3700	3705
254.	Dark shale and dark bituminous dolomite as above	3705	3710
255.	Black and green shale, dark gray dolomite. Both bituminous. Dolomite contains crystalline anhydrite	3710	3715
256.	Dark gray shale, dark buff gray bituminous dolomite. In thin section the dolomite shows a profusion of organic fragments in dim outlines in the arrangement of crystals and inclusions of anhydrite	3715	3720
257.	Dark dolomite, and green, gray to black shale. Heated in closed tube fumes of ammonia, sulphur, and bitumen are given off	3735	3740
258.	Dark gray dolomite and dark gray shale. Pyrite noted in dolomite. In thin section the rock is seen to have minute black streaks, and to be fine in texture, crystals measuring about 0.01 mm. in diameter. Driller's note: "Unusually hard limestone." Ammodiscus noted. Bituminous fumes given off when heated in closed tubes	3755	3760
259.	Dark dolomite and green, gray to black shale, which yields sulphur, oil and ammonia fumes in mattrass	3765	3770
260.	Dark dolomite and green, gray to black shale. One Ammodiscus noted. Ammonia fumes noted in closed tube. Distils oil and gas under same conditions	3775	3780

		Feet From.	To.
261.	Yellowish to black dolomite, and greenish, gray to black shale. Sulphur and ammonia fumes given off when heated in closed tube. Ammodiscus noted, three specimens	3795	3800
262.	Dark brownish gray dolomite and green and black shale. Fumes of oil, sulphur and ammonia are given off on heating in closed tube. Some anhydrite present	3810	3815
263.	Dark gray dolomite, consisting of crystals 0.01 to 0.02 mm. in diameter and containing very little anhydrite. Black shale is present. The sample yields bituminous, sulphurous, and ammoniacal fumes when heated in a closed tube. Ammodiscus noted	3820	3825
264.	Dark gray dolomite with some dark, some greenish and some black shale. On heating in closed tube oil, sulphur and ammonia fumes are given off	3830	3840
265.	Dark grayish yellow dolomite and some greenish and black shale. Flat Ammodiscus noted. Sulphurous, bituminous and ammoniacal fumes are given off on heating in closed tube. In thin section some dolomite is seen to consist of crystals about 0.05 mm. in diameter, fairly uniform, some consists of crystals of variable size and clearness, giving indistinct outlines of original organic fragments, some being crescentic, and some fragments show bodies resembling oolitic spherules and encrusted organic fragments imbedded in a copious matrix of anhydrite	3850	3855
266.	Mostly yellowish gray dolomite. In thin section some fragments show crystals quite uniformly about 0.06 mm. in diameter. Two fragments consisted of crystals about 0.02 to 0.04 mm. in diameter, clustered in such a manner as to indicate that the original rock consisted of organic or other fragments. Some straight elongated indistinct structures were noted, resembling spicules of sponges. One fragment had many small cavities filled with anhydrite	3860	3865
267.	Dolomite and shale	3865	3870

	Feet From.	To.
268. Yellowish gray dolomite. In thin section one fragment is seen to consist of bodies of dolomite traversed and surrounded by tracts of anhydrite, and in another fragment there are pockets filled with anhydrite and also porosities in the rock	3875	3880
269. Yellowish gray dolomite. In thin sections three fragments were each of uniform sized crystals. In one these were about 0.02 mm. in diameter, another about 0.04, and another about 0.1. The finer textured specimens had the crystals in groups indicating some granular feature in the original rock. Pockets of anhydrite were noted in one sample, and also traces of spicular structure	3885	3890
270. Yellowish gray dolomite of coarse texture, and some dark shale. This shale was found to contain an Ammodiscus. Fumes of ammonia and sulphur noted on heating in closed tube	3900	3905
271. Yellowish gray dolomite and some black shale. Fumes of sulphur and ammonia are given off on heating in closed tube	3915	3920
272. Gray dolomite and some black shale. In thin section the crystals of the dolomite are seen to have a quite uniform size, about 0.04 mm. in diameter. Marks of some probable organic structure like sponge spicules were noted. There were also distinct small crevices filled with what appeared to be anhydrite. In closed tube, on heating, faint bituminous fumes were noted and stronger fumes of sulphur and ammonia	3930	3935
272a. Dolomite and some black shale, pyrite noted	3935	3940
273. Yellowish gray dolomite and some green and dark shale. Fumes of oil, sulphur, and ammonia noted on heating in closed tube. Spicule noted in thin section	3945	3950
274. Yellowish gray dolomite and black and gray shale. Flint, yellowish in transmitted light, noted	3965	3970
274a. Like the following	3980	3985
275. Gray dolomite. In thin sections three fragments were seen to consist of uniform sized crystals measuring about 0.03 mm. in diameter. Some anhydrite was also seen in the		

		Feet From.	To.
	thin section, occurring as fillings in irregular cavities. In one place it was clearly associated with red ferruginous material. The dolomite, when heated in tube, gives off faint fumes of bitumen, sulphur, and ammonia	3985	3990
276.	Dolomite and shale	3995	4000
276a.	Mostly gray dolomite. In thin section four fragments were seen to consist of fairly uniform crystals measuring about 0.03 mm. in diameter. No anhydrite noted. Fumes of ammonia, oil and sulphur, on heating in closed tube	4005	4010
277.	Dolomite and some shale	4020	4025
278.	Dolomite, in part quite coarse-grained, and some shale	4025	4030
279.	Dolomite, some with quite coarse crystals, some light gray chert, and some shale	4030	4035
280.	Dolomite, some porous. Also some shale	4035	4040
281.	Yellow and gray dolomite, some porous. Some shale	4040	4045
282.	Dolomite and shale	4050	4055
283.	Dolomite, some fragments slightly porous, shale black, green and gray	4060	4065
284.	Yellowish dark gray dolomite, chloritic greenish black shale; black, dark gray, gray and green shale. Plate 13, A	4070	4075
285.	Dark gray dolomite, giving ammonia and sulphur fumes in closed tube. Not much shale. In thin section the dolomite is seen to consist of crystals about 0.1 mm. in diameter	4075	4080
286.	Yellowish gray dolomite, some green and black shale	4080	4085
287.	Yellowish gray dolomite and a little black and green shale. In thin section the dolomite is seen to consist of crystals measuring about 0.05 to 0.08 mm. in diameter, and to have small crevices filled with anhydrite. Plate 13, B	4085	4090
288.	Dolomite, yellowish dark gray. Fragments of anhydrite noted, also green and black shale. The black shale has minute shreds of vegetation	4090	4095

		Feet From.	Feet To.
289.	Dark yellowish gray dolomite and some white limestone. (First seen.) The dolomite is seen to consist of crystals about 0.1 mm. in diameter. Some fine textured white anhydrite noted, and some white chert which has a brown color in transmitted light	4100	4105
290.	Mostly yellowish gray dolomite and green and dark shale. A few fragments of white calcareous fragmental limestone noted, one with a Fusulina. There is also some white chert. Spicule of sponge noted	4110	4115
291.	Mostly dolomite. Some white limestone. Fusulina not noted	4120	4125
292.	Much of the sample is dolomite and shale. A white limestone has Fusulina. There is considerable white flint, apparently occurring with the white limestone	4130	4135
293.	Most of the sample is yellowish gray dolomite. Some is greenish and black shale. The rock in which the drill has worked at this depth is a white limestone consisting of organic fragments in a more or less copious matrix of calcite. In this were noted Fusulina, a Nodosaria, and a bryozoan	4140	4145
294.	White limestone containing Fusulina. Flint and black and greenish gray shale are also present. A flat Ammodiscus noted	4150	4155
295.	The principal ingredient is a white and oolitic limestone. This consists of organic fragments, which are grouped in small clusters. Fossils noted in this limestone: Fusulina, Rhombopora (?), crinoid stems, valves of ostracods (?), a foraminifer like a Nodosaria, with shallow and wide chambers. Flint and dark shale noted	4160	4165
296.	White and gray limestone containing Fusulina and some fragments of other fossils. Also some dark shale	4170	4175
297.	White, yellow and gray limestone, and greenish gray and black shale. The black shale shows small shreds of vegetation. Fusulina, sponge spicules, and pinnules of crinoids noted	4180	4185
298.	Grayish and white limestone. Fossils scarce. Fusulina, spicules of sponges, and a Nodosaria noted. Bluish white chert present	4185	4190

		Feet From.	To.
299.	White limestone. Some fragments of a minutely porous yellowish magnesian limestone noted. Fragments of a crinoid stem, of sponge spicules, a Textularia jonesii noted. Bluish chert present	4195	4200
300.	Dark gray fragmental limestone with white limestone. Bluish white chert seen, with concentric, botryoidal structure as in agate. Fusulina, sponge spicules and many obscure fossil fragments noted	4205	4210
301.	Moderately dark gray limestone. Fusulina, sponge spicules, fragments of bryozoa noted. A thin section of the rock shows it to consist of calcite crystals of variable mixed sizes, some aggregations of more even and larger sizes than the average, no doubt representing places of imbedded fossil fragments, traces of which clearly appear in the grouping of crystals in some places. In the mass are imbedded brownish and black shreds and stains of bituminous material	4215	4220
302.	Gray and faintly yellowish light limestone. Fusulina frequent, also sponge spicules. Crinoid stem and denticle of annelid,* and a Nodosaria noted	4225	4230
303.	Dark gray limestone, containing minute black fragments, 0.10 mm. in length. Sponge spicules and a meandering (tubular?) structure noted	4235	4240
304.	Dark gray limestone, with some yellowish white limestone and some bluish flint. Pinnules of crinoids, spicules of sponges, disc-shaped flat bodies, and a Nodosaria noted	4250	4255
305.	Dark gray limestone, showing minute black specks, with some white limestone and flint. Spine of brachiopod, many sponge spicules, Textularia jonesii, a flat Ammodiscus of two coils, a fragment of some large shell, a crinoid pinnule, a minute curving tube noted, the latter in the dark limestone	4260	4265
306.	Some fragments of ferruginous brown and yellow limestone, with dark gray and white limestone as in preceding samples. A piece of the brown rock, in thin section, is seen to		

*Denticles of Annelids are now known as *conodonts.*

	Feet From.	To.
be finely fragmental, stained in spots with brown, contains black specks, like the gray rock in the preceding samples, shows many imbedded obscure organic fragments which are filled with crystalline calcite. Fossils: An ostracod, Nodosaria, a small Ammodiscus, with two varicose whorls, many sponge spicules, several with rounded ends	4265	4270
307. Blotchy brown and gray limestone, with bluish white flint, all as in preceding sample. Fossils: Rhombopora lepidodendroides in flint, Nodosaria, Textularia, Ammodiscus, flat, an ostracod, Serpula (?). Sponge spicules frequent. Fragment of brachiopod shell seen	4275	4280
308. Limestone, bluish white, yellow and dark gray. A fragment of the bluish white limestone in thin section is seen to be an organic fragmental rock, in which are many fragments of fossils, changed to crystalline calcite. The change has partly affected the matrix also, which is mostly finely granular. Many black specks noted. Fossils: Crinoid pinnule, Fusulina cylindrica (?), Nodosellina, sponge spicules, Nodosaria sp., Nodosaria radicula, Trochammina gordialis. Plate 12, C	4285	4290
309. Dark gray limestone effervescing somewhat slowly in acid. Fossils: Crinoid pinnules and stem, sponge spicules, Nodosaria radicula, flat Ammodiscus	4295	4300
310. Limestone, some white, some gray and some yellow. Fossils: Spicules of sponges, one clearly a hexactinellid, a Nodosaria, near radicula, and Trochammina gordialis	4305	4310
311. Most of the rock is a white limestone. In thin section one fragment consists of finely granular material in which are irregular traversions of more coarsely crystalline portions. Another fragment is almost wholly of finely granular material. In both obscure and more clear outlines of organic fragments occur. Very few black specks were seen, all exceedingly minute. Fossils: Fragments of crinoid stems, and of bryozoa, spicules of sponges, Climacammina antiqua and Endothyra ammonoides (?)	4315	4320

		Feet From.	Feet To.
312.	White, yellow and gray limestone. Some of the white limestone is quite porous. Several Fusulina fragments present. Other fossils few: Trochammina gordialis, hexactinellid sponge spicules, Nodosaria sp., fragments of brachiopod shells and of bryozoa	4320	4325
313.	Mostly white limestone which contains Fusulina. The rock is finely granular and contains imbedded organic fragments which have not been crystallized. Fossils: Sponge spicules, Nodosaria, a flat Ammodiscus	4330	4335
314.	Mostly white limestone, containing Fusulina. Other fossils: Nodosaria, Endothyra, flat Ammodiscus, Nodosaria radicula, sponge spicules, one small circular disc	4340	4345
315.	Mostly yellowish white limestone. In thin section it is seen to contain Fusulina and fragments of other fossils imbedded in a granular mass of very finely crystalline calcite, through which are scattered calcite crystals of ten times larger size. In water the sample behaves as if it were oily. In a closed tube it emits bituminous fumes, and in the oxygen flame the white limestone at first turns black, evidently from carbonaceous material. Fossils: Endothyra, sponge spicules and Nodosaria and Fusulina	4350	4355
316.	White limestone like that in the preceding sample. Fossils: Endothyra, Ammodiscus, a very broad and tapering Nodosaria (?), crinoid stem fragments, spicules of sponges	4360	4365
317.	Cream-yellow organic limestone. Some flint present, bluish white, but brown in transmitted light. Fusulina, a large flat Ammodiscus, bryozoan fragment, sponge spicules, denticle of annelid, two species of Nodosaria, Textularia, like jonesi, and other foraminifera noted	4365	4370
318.	Limestone like that in preceding sample. Some dark shale. Fossils: Nodosaria, ostracods, Ammodiscus, spicules of sponges	4375	4380
319.	White organic limestone, which darkens in closed tube. Fossils are abundant, such as Textularia, Endothyra, Ammodiscus, Tro-		

		Feet From.	To.
	chammina gordialis, fragments of bryozoa, spicules of sponges, pinnules of crinoids, Nodosellina priscina (?), and cylindrica, etc.	4385	4390
320.	Grayish white and white limestone and black shale. The limestone resembles that in the preceding samples. The shale yields ammonia fumes in closed tube, fumes of sulphur and also faint bituminous fumes. Fossils are frequent, and of same kinds as in the preceding samples	4395	4400
321.	Black shale and some gray limestone. The shale gives off strong ammonia fumes when heated in closed tube, and also sulphurous fumes. Pyrite noted. Fossils: Contorted forms of Trochammina are frequent. Ammodiscus, various forms of Nodosaria, sponge spicules, fragments of bryozoa and a crinoid joint noted	4400	4410
322.	Shale and some gray limestone. On heating in closed tube, faint bituminous fumes were noted, and fumes of sulphur and ammonia. The limestone darkens on heating. Fusulina present, also some pyrite. Fossils are quite abundant, essentially as in the preceding sample	4415	4420
323.	Rock and fossils as in preceding sample	4425	4430
324.	Black shale giving sulphurous and ammonia fumes on heating in closed tube. Very little limestone. Fossils: Ostracods, Nodosaria, Ammodiscus, Endothyra, Lagena, sponge spicules, Trochammina gordialis	4435	4440
325.	Black shale and some gray limestone. Fossils about as in preceding sample. Some round discs and some branching tubes noted	4445	4450
326.	Black shale, yielding oil, sulphur and ammonia fumes when heated in closed tube, and some very white limestone. Fossils about as in preceding sample. Crinoid pinnules noted	4455	4460
327.	Black shale, some dark gray shale and some white limestone. In thin section the white limestone is seen to consist of mostly finely granular crystalline calcareous material. In this are some larger crystals of calcite. In the arrangement of the granular material dim outlines of organic fragments		

	Feet From.	To.
clearly appear. Fossils: Some circular and oval discs were noted, having irregular central cavities filled with opaque material. They have a resemblance to Valvulina rudis. Trochammina, Nodosaria, Ammondiscus, a peculiar spine, probably from a crinoid, spicules of sponges and ostracods noted. Gives fumes of ammonia and sulphur in closed tube	4465	4470
328. Black and dark gray shale and light gray limestone. Fossils about the same as in the preceding sample. Valvulina rudis and a young brachiopod, probably Ambocoelia planoconvexa, noted. Gives fumes of sulphur in closed tube	4475	4480
329. Mostly black shale, with some limestone. Fossils like those in preceding samples and in addition young brachiopods; one showing both beaks (Ambocoelia planoconvexa?) and one like a young chonetes, a young pelecypod showing beaks of both valves, fragments of crinoid stems, and a fluted and tuberculated spine like the spine of an Archeocidaris. Gives fumes of oil and sulphur in closed tube	4480	4485
330. Black and dark gray shale, giving oil and sulphur and ammonia fumes when heated in a closed tube; white and gray limestone in small quantity. This sample contains some rounded quartz sand grains, mostly from ½ to ¼ mm. in diameter. Some chert present in this and preceding samples. Fossils as in the preceding two samples	4485	4489

THE FORMATIONS EXPLORED IN THE SPUR BORING

The strata explored by this boring constitute three well marked divisions. The upper 1250 feet consist of red sands, clays, marls, beds of gypsum, anhydrite and salt, all in different gradations of purity and intermixture. This is the Permian Red Beds, constituting a part of the Double Mountain formation. The succeeding 2850 feet consist of dolomite, with strata of anhydrite, sandstone and shale. These are probably to be correlated with the Delaware

formation west of the Pecos and are, no doubt, the equivalent of the Wichita and the Albany, the Clear Fork and part of the Double Mountain formation. The lowest 389 feet of the section explored consist of limestone and shale, which are believed to correspond to the upper part of the Cisco formation of central Texas. These beds are here described in the order of the work of the drill, from above downward. It will be understood that the drift and possible Triassic present near the surface are neglected on this account.

THE RED BEDS

Upper Part

The uppermost 300 feet of the Red Beds consist of fine silt and clay impregnated with iron oxide, which gives it mostly a deep red color. The greater part of this deposit consists of grains measuring from one to four hundredths of a millimeter in diameter. The interstitial spaces are filled with ferruginous material of a much finer grade, and this makes the mass relatively impervious to water. These beds contain some interlaminated and concretionary gypsum and also concretionary and, possibly, in part stratified, calcareous material. At some depths the calcareous ingredient is diffused throughout the silt, making it marly. Near beds of gypsum and anhydrite, which this deposit contains, the clays are blotched and streaked with greenish and bluish gray color. At 135 feet below the curb, such a streak of blue gray was reported by the driller.

Middle Part

From 400 to 900 feet below the surface the Red Beds consist for the most part of fine red sand or sandstone. Some of these strata are only very slightly coarser than the red clays, and nearly all this rock has more or less red silt and ochreous material filling the interstitial spaces among the sand-grains. The coarsest sand was at from

403 to 468 feet, where the rock contained some fine gravel, and at 580 and at 680 feet, where it consisted for the most part of grains measuring from one-fourth to one millimeter in diameter. Calcareous material is present in the sand and appears to be derived from concretions. White streaks or blotches are to be seen on some of the fragments of the sandstone samples, especially near beds of anhydrite. Apparently the sand contains thin layers of gypsum, or it is impregnated with gypsum or anhydrite. At some depths it contains a few scales of mica. Two minerals which appear to be common in the coarser strata are crystals of anhydrite and of quartz, few of which measure more than one millimeter in length, when not in clusters. Small crystals of selenite are also quite common. The sand grains are only moderately rounded. Their surface is in many cases slightly etched, and nearly always it has some adherent ochreous red matter. The quartz itself is a clear variety.

Lower Part

The lower 350 feet of the Red Beds consist of a sandy silt mixed with varying amounts of salt, in which the sand and silt particles are imbedded as in a matrix. Some coarse, almost gravelly sand occurs at from 1174 to 1222 feet below the surface. From determinations of eight samples of the salty rock, its salt content was found to range from 15 to 67 per cent, and to average 36 per cent. The salt has an extensively crystalline structure. It shows reflexions of light from cleavage surfaces, which are continuous across a core six inches in diameter. The greater part of this peculiar salt and sand rock is red, and resembles the finer strata of sandstone. Greenish gray circular spots and streaks occur near beds of anhydrite. Some of the rock is laminated, but it mostly has a marked homogeneous texture. Cores several feet in length were taken from these beds. When exposed to the atmosphere, the salt is slowly volatilized on the surface of the rock, and the contained silt is set free and falls off, causing the rock to disintegrate slowly.

Salt of the Red Beds

There were three beds of pure salt; one ten feet thick, from 570 to 580 feet below the surface; another five feet thick, from 633 to 638 feet; and a third nine feet thick, from 732 to 741 feet. The upper bed consists of white granular salt showing thin red seams about a half millimeter apart, due to the presence of red silt. The lowermost bed is clear, crystalline salt which is transparent, except for imbedded blotches of silt which shows no well-marked stratification.

Assuming that the salt-sand in the lower part of the Red Beds measures 290 feet in thickness and contains 36 per cent of salt, the thickness of a stratum representing all the salt shown in the section would be 128 feet for the entire section. Five-sixths of this salt is in the lower half of the Red Beds.

Gypsum and Anhydrite

At Spur, as elsewhere, the most characteristic persistent ingredient in the sediments of the Red Beds consists of calcium sulphate minerals, gypsum and anhydrite. Beds of this kind occur from ten to a hundred feet apart throughout the section, in the sandstones, in the clays, and in the salt beds. There are no less than eighteen separate strata in the 1150 feet of all sediments. The thickest bed of anhydrite lies from 330 to 403 feet below the surface, measuring 73 feet. Another bed measures 30 feet and lies from 540 to 570 feet below the surface; another is 25 feet thick at from 603 to 628 feet, and one of nearly 25 feet below the depth of 1175 feet. Nine beds are five feet thick or less, four are from six to ten feet, and two from eleven to fifteen feet. The combined thickness of all the gypsum and anhydrite in the section is at least 250 feet. Four-fifths of this thickness lie in the upper half of the Red Beds and the lower part of the heaviest deposits of anhydrite are interbedded with the uppermost, thinnest and purest salt beds.

The thickness of strata of mechanical sediments separating any two beds of gypsum and anhydrite from each

other are, in feet, as follows, allowances being made for salt contents: 101 (coarsest sand), 55, 43, 41, 40, 40, 37, 34, 31, 23, 22, 17, 16, 11, 8, 7, 7, 5.

The hydrated form of the sulphate occurs in the upper 285 feet of the boring, in the main body of the finer shaly sediments. There are in all seven beds of gypsum, from one to fifteen feet thick. Some of the gypsum is granular and white, and some is coarsely crystalline. It is the latter variety which is called isinglass, by the driller. Red impurities are seen in both forms. Between 285 and 298 feet below the surface is a bed consisting mainly of compact anhydrite but containing also some gypsum. Below this depth nearly all sulphate of calcium occurs as anhydrite. Some anhydrite is finely granular and white, but most is very compact and some is semi-transparent. At some depths, it is stained red or greenish-gray by silty impurities, and a sample from 992 feet below the surface contained inmbedded grains of quartz. Salt is also present as an impurity, especially in anhydrite containing layers and streaks of sandy or silty admixtures. Anhydrite of this kind was noted at 1005 feet.

Calcareous Material

Calcareous material is an inconspicuous part in the lower 900 feet of the Red Beds. Fragments of a red granular limestone were noted at 540 feet, and there were calcareous fragments at 603 feet and again at 633 feet. These may have come from layers of limestone, as is believed to have been the case at 540 feet, or the matrial may represent concretions.

General Character of the Red Bed Sediments

Mechanical sediments make little more than two-thirds of the Red Beds explored in this boring. The rest consists of chemical sediments. The percentages of each kind of these sediments in the complex of the formation are about as follows:

	Per cent
Gravelly sandstone and sand	5
Sandstone and sand	36
Clay and shale	13
Anhydrite	18
Gypsum	3
Sand and salt, mixed	21
Salt	4

THE DOLOMITE BEDS

From 1250 feet below the surface down to 4095 feet the drill was going through what is essentially a formation of dolomites, interrupted by beds of sandstone, shale and anhydrite, the last of which is to some extent of secondary origin. The thickness of this series is 2845 feet. The persistent feature which makes this formation appear somewhat as a unit is its dolomitic character. On the basis of the nature of its minor elements, the formation may be divided into an upper part, 1730 feet thick, where the prevailing minor beds consist of sand and anhydrite, and a lower part, 1115 feet thick, in which the minor beds consist of shale. We may refer to these respectively as the sandy and the shaly dolomite beds, although it should be understood that both of these accessory rocks are present as separate beds.

THE DOLOMITE

Crystalline Texture

As to the size of crystals, the dolomite is of fine texture throughout the entire formation. Most of it is very fine in texture. Measurements on the size of the crystals, the grains of the rock, have been made at 15 depths, somewhat arbitrarily selected. It appears that there is a general increase in sizes with depths, as will be evident from the list of the measurements made, and here inserted.

Sizes of Dolomite Crystals

Depths in feet below surface, of rock examined	Average sizes of crystals in thousandths of mm.
1600	10
1800	5
1800	10
2214	5
2392	10
2624	7
3046	8
3335	20
3335	30
3520	5
3715	10
3760	10
3820	20
3855	50
3865	20
3865	40
3855	60
3930	40
3985	30
4010	30
4080	100
4090	50
4090	80
4095	100

It will be seen that in the lowermost two hundred feet there is a decided increase in the size of the crystals. The coarsest dolomite is in the lower part of the formation, which rests on limestone. At most depths the crystals are of approximately uniform size. At 3405 feet below the surface the crystals are more or less grouped in clusters, as if agglutinating into new and larger bodies. At 3335 feet such a recrystallization has apparently resulted in uniformly larger crystals in most of the rock, but there remain in the coarser mass some island-like bodies that

are sharply marked off from the rest of the rock by their finer texture. Nearly all the dolomite is compact. Porous rock is rarely seen, and when found, the porosities are very small. Dolomite with minute open spaces was noted at 1600, 2476, 3355 and at from 4035 to 4065 feet below the surface. The upper part of the dolomite is known to consist, in part, of thick beds. At the depth of 1600 feet a single piece of core was taken out which measured sixteen feet. A core of this length would have been broken in the process of cutting, if there had been any marked horizontal seams of bedding in the rock from which it was taken.

Chemical Composition

The dolomitic character of the rock is known from the fact that it is throughout comparatively resistant to dilute hydrochloric acid, nearly every sample having been tested in this respect. It is also known from the crystalline texture seen in nearly two hundred thin sections. Though this texture mostly is fine it is seen, in sufficient magnification, to be of the kind which characterizes all dolomites. A sample from the depth of 2264 feet, which to the unaided eye appears very much like limestone, was readily identified as dolomite by its optical properties. An analysis of the same sample made by Mr. S. H. Worrell, Chemist of the Bureau of Economic Geology and Technology, was accompanied by the note that the sample was a mixture of sulphate of lime and the double carbonate of lime and magnesia. This analysis is as below.

Analysis of a Piece of Core from the Depth of 2264 Feet in the Spur Boring, Spur, Dickens County, Texas

Lime as sulphate of lime	30.19
Lime as carbonate of lime	29.34
Magnesia as carbonate of magnesium	22.24
Undetermined	18.24

Clastic Texture

The process of dolomitization has left much of the original clastic structure of these sediments in a condition yet to be made out. While the rock consists of minute dolomite crystals, the change has not always obliterated the forms of the particles of which it was to some extent originally composed. Some of the original rock was oolitic, and some must have consisted largely of small organic fragments. (Plate 11, B, C, 5 and 7.) Some was perhaps a structureless calcareous slime, for much of the dolomite exhibits no traces of original clastic structure, other than indistinct lines of bedding planes.

Oolitic Dolomite

Between the depths of 1250 and 2050 feet only a few samples of rock were received from known depths. It is doubtful if any of the rock samples examined came from the upper 350 feet of this interval. From 1600 feet down to 3120 feet, much of the dolomite is oolitic. Oolite is present in the samples from 1800, 2250 to 2264, 2600 to 2624, 2709 to 2735, 2751 to 2956, 3050 to 3055, and from 3115 to 3120 feet below the surface. Plates 1A, 3, 5, 6, 7, 8, 9B, 10A. Original oolitic structure is indicated in several samples by a peculiar grouping of the crystals of the dolomite, where bodies of the common sizes of oolite grains exhibit a finer, and more compact texture, than the rest of the rock in which they lie imbedded. Such texture was noted at from 2271 to 2329 feet, from 2539 to 2548, and from 2900 to 2950 feet below the surface. The oolitic texture has, in some cases, been blurred, as it were, in the process of dolomitization. Plates 1, 2, 3, 10A and 11A.

The oolitic spherules are of variable form, appearing circular, oval, or elongated in a section. Commonly their lesser diameter is two-thirds the length of their greater diameter, but it is in many cases much less than this. Their outline is mostly oval or circular, but it may have any shape, crescentic, triangular, polygonal, always with rounded

angles. The spherules seldom show any nucleus and not usually concentric structure. Some are merely incrustations enveloping fragments of small shells and of bryozoa. (Plate 7.) Their form is marked by mostly a single external layer some 0.05 mm. in thickness. In a few cases the largest spherules were seen to inclose two or three smaller ones, each having their own external layer, inside of the outer layer inclosing them all. Figs. 1, 2, and Plates 1A, 3, 5, 6 7, 8, 9B, 10A.

The oolitic grains are small in size in all of these rocks, too small to be readily made out without a good hand lens. This appears, from some measurements made, as below:

Measurements of Sizes of Oolitic Spherules

Depth, in feet below surface	Size of longer diam., in 10ths of a mm.	Size of shorter diam., in 10ths of a mm.
1800	8.6	6.6
1800	6.9	4.5
2250–2264	11.1	1.7
	9.4	5.1
	7.7	4.7
	6.9	4.7
	6.0	3.4
	4.3	4.3
	3.4	2.6
	2.1	1.7
2606–2609	6.5	3.4
	5.6	2.1
	4.3	3.0
	3.8	2.5
	3.8	1.7
	3.4	3.4
	3.4	2.6
	3.4	2.1
	2.6	1.7
	2.1	2.1
2609–2624	6.5	2.1
	5.6	3.0
	1.7	1.3

2709–2735	5.2	3.4
	2.6	3.1
	2.1	2.1
2900–2950	6.9	5.2
	3.0	1.3
	2.6	1.7
	2.1	2.1
	1.7	1.3
3050–3055	5.2	3.4
	1.7	1.7
3115–3120	4.3	2.6
	3.4	3.4
	2.6	1.3
	2.1	2.1

Most of the oolitic rock contains fragments of organic remains mingled with the spherules, some with and some without an oolitic incrustation. Fig. 2. The ratio between the quantities of spherules and matrix is variable within wide limits.

Dolomite of Fragmental and Other Texture

Some dolomite exhibits a minute concretionary structure, where bodies of fine-grained dolomite are separated from each other by a matrix of relatively coarse grain; but where the nodular bodies lack the uniformity of size as well as roundness of form, which characterizes oolitic spherules. (Plate 11C.) Most of these textures probably had their origin in the clastic structure of the original limestone which may have been an organic sand or silt, composed of imperfectly sorted grains. (Plate 7.) Other specimens seem more likely to have been concretionary, as the fine-grained particles are more generally spherical in form, though lacking the smoothness and the uniformity in size which characterize oolitic spherules. (Fig. 1.) Textures of these several kinds occur at 1600 feet, from 2751 to 2900, 2900 to 2950, 3185 to 3190, 3515 to 3520, 3715 to 3720, 3860 to 3865, 3885 to 3890, and at some other depths. In several

samples traces of organic fragments, such as gently curving intersections of small shells and the straight outlines apparently of spicules of sponges, appear in the grouping of crystals of the rock. (Plate 9A and B.) Such were noted at from 2673 to 2677, 2950 to 2956, 3335 to 3340, 3185 to 3190, 3515 to 3520, 3545 to 3550 feet, and at several other depths.

A unique texture was noted in one of the samples coming from between 1250 to 2040 feet below the surface, its exact horizon not being known. At first sight this impure dolomite appears to be a thinly laminated rock. On close examination a vertical section is seen to exhibit thin lenticular bodies separated from each other by a matrix. The rock is impregnated with bituminous and other opaque impurities. It would appear that such a structure and such residue of impurities might result from the leaching out of much of the calcareous material in an oolite under pressure of the weight of overlying strata. (Plate 1B, Fig. 3.)

Distribution of Textures

All of the textures described occur both intermingled and separately. One-fourth of the samples show no other texture than that of its crystalline make-up and of obscure stratification. Such rock occurs throughout the series as at 2050, 2550, 2725, 3175, 3200, 3225, 3525 feet, and several other depths. (Plates 10B and 12A and B.) Organic fragmental rock also containing oolitic spherules were noted at 2950 to 2956 feet, 2995 to 2996, 3050 to 3055, 3185 to 3190, 3245 to 3250, 3305 to 3310, 3545 to 3550, 3630 to 3635, and 3715 to 4720 feet below the surface. Figs. 1 and 2, Plates 7, 9B, 11B.

In general, oolitic beds are found mostly only in the sandy dolomite from 1250 to 3120 feet, and indications of clastic organic texture are most common in the shaly dolomite from 3120 feet to the base of the formation.

Interbedded Sands

The main accessory sediments in the dolomitic beds are sand, shale and anhydrite.

Small beds of sand are reported by the driller in the upper part of the dolomite as follows:

	Depths in feet below surface	Thickness, in feet.
1.	1538–1546	8
2.	1827–1830	3
3.	1860–1862	2
4.	1877–1884	7
5.	1988–1992	4
6.	2047–2049	2
7.	2392–2395	3
8.	2396–2401	5
9.	2472–2480	8
10.	2541–2551	10

None of these beds exceed ten feet. Only three of them, 1, 6, and 7, are reported unequivocally as consisting of sand only. Numbers 2 and 3 are called sand and flint. In 4 and 5, sand is mentioned as occurring with blue rock. Numbers 6, 7, and 8, so far as known from samples, are beds of red sandy clay or silt. In the samples from numbers 9 and 10, no sand appears, except some stray grains of quartz. The samples at all these depths were selected and are not representative for all depths.

At two other depths the samples demonstrate the presence of considerable beds of sandstone. The uppermost is from 2069 to 2110 feet, and from 2128 to 2212 feet. Samples taken from these depths consist mostly of ferruginous red clay, which contains some fine sand, the grains measuring mostly from 0.1 to 0.2 mm. in diameter. Some mica is also present here. The other sand rocks appear in the samples at from 2644 to 2660, from 2664 to 2673, and from 2735 to 2751 feet, below the surface. These sandy beds also contain much red clay, and the sand is of fine texture. In

the lower group of red sandy shale, from 2664 to 2751 feet, there is also some very dark gray, and almost black shale. The two and a half hundred feet of sand reported by the driller below 2751 feet is probably partly dolomite, containing minor beds of sand. The dolomite is largely oolitic at this depth.

It is significant of the relationship of these sediments to the Red Beds above that their sandy clay beds are both ferruginous and of nearly the same mechanical composition as in the Red Beds. Below 2800 feet these red clayey sands do not occur. In the Red Beds the sands and clays, and even some gypsum and anhydrite, are mostly of a deep red color. The red color of the ferruginous sands between 2000 and 2700 feet decreases in brightness downward and becomes brownish. It appears that in some of the red or brown rocks reported in shale and dolomite below the depth of 3000 feet the coloring has not affected the entire rock but belongs to separate layers, or the color is present in spots or blotches; for some fragments show blue as well as brown color.

The combined thickness of beds of red clayey sands in the dolomite formation is estimated not to exceed 300 feet.

Interbedded Shale

The only shaly material reported by the driller from the oolitic upper part of the dolomitic beds evidently was present as thin seams in the main rock. At from 1397 to 1403 feet, there were soft blue streaks in dolomite. Soft streaks were encountered in the same kind of rock at from 1425 to 1433 feet, and from 1454 to 1461 feet. Blue sandy and shaly rock was noted at from 1546 to 1551 feet. In the lower division of the dolomite shale is noted at two depths, from 3060 to 3075 feet and from 3667 to 3669 feet. The presence of shale at the last two depths is also shown by the speed attained in drilling, which increased much for the space of nearly a hundred feet below the depth of 3060 feet, and increased slightly for a short distance below 3660 feet.

Examining the cuttings, much more shale is found than would be expected from the driller's record. But few

samples are without shale, and many consist of more shale than dolomite. To some considerable extent this is no doubt due to caving, material from soft shaly strata falling from the walls of the hole to be ground up by the bit and later to appear in the returns.

But it is doubtful that all of the shale present can be accounted for in this way. This appears from the recorded rate of drilling. Below 3067 feet this rate rose from 6 and 7 feet per day, the usual rate in limestone, to 18, 20, 20, 16, 17, 14, and 13 feet for the succeeding seven days of drilling. After this the rate continued at an average of about ten feet per day for the next thousand feet. Even in this more steady rate there were considerable variations; from 6 and 7 feet some days, to twice these figures. It is believed that these minor differences were due mainly to the presence in the dolomite of layers of shale that, for the most part, were too thin to attract particular attenion.

Equally strong evidence of such conditions the writer finds in the nature of the shale itself present in the samples. The heaviest shale reported by Mr. Minihan at from 3060 to 3075 feet is a dark gray and dark green-gray shale, that lacks other characteristics. Such shale occurs all the way down. Black shale is not seen until the depth of 3235 feet, and below 3700 feet black shale is more frequent than above this depth. Shale of light gray color is more frequent from 3350 to 3500 feet than either above or below this horizon. Bluish-gray shale is more in evidence at from 3200 to 3325 and from 3450 to 3560 feet, than either above or below these depths. Shale containing shreds of imbedded vegetation in the form of "natural charcoal" was noted four times between 3555 and 3620 feet, and once near 4090 feet, but at no other depths. Thinly laminated shale is seen in three samples between 3535 and 3620 feet, but is not present elsewhere. Pyrite occurs in shale of a sample taken at from 3200 to 3205 feet, and was noted also in anhydrite in a sample taken ten feet below this. Mica was noted in two samples taken from between 3630 and 3640 feet. Both of these minerals are no doubt present in much of the shale, but not in particles large enough to be conspicuous. All of these circumstances are believed to warrant the conclusion

that much of the shale present with the dolomite throughout the section belongs to the rock with which it comes. If all this shale were the result of caving from one or two levels, it would be of a more uniform character.

In the absence of sufficient data for estimating how much of the shale in the samples has been introduced by caving, it is not believed that an estimate on the total contents of shale would be warranted, farther than that a combined thickness of 200 feet of shale appears to be a safe minimum.

Anhydrite

Through the whole dolomite formation, anhydrite is a considerable ingredient in all samples. As this rock does not cave, it is believed that the quantity of it present in the samples correctly represents its quantity in the section, relatively to the dolomite and the sandstone.

The scarcity of samples from 1250 to 2040 feet prevents any close estimate as to what part of the rock between these two depths was anhydrite. There may have been a large proportion of anhydrite. The sample from 1235 to 1250 feet is mainly anhydrite. At 1950 feet the core consisted of an almost pure and translucent compact anhydrite, of bluish-gray color. Most of the rock in this part of the boring is reported by Mr. Minihan as "rock," and not as limestone. This suggests that it was a rock different from limestone. Anhydrite is reported in similar terms at from 2064 to 2068 feet. At a few other depths it is undoubtedly reported as limestone. As nine of the ten samples selected to represent the strata from 1250 to 2040 feet consist of dolomite, and only one is anhydrite, the presumption is, nevertheless, that there was considerably more dolomite than anhydrite.

From 2040 down to 4095 feet at least twenty-five per cent of the formation is anhydrite, as near as can be judged from the data at hand. It is also clear that there is much more anhydrite in the upper oolitic and sandy dolomite than in the lower and shaly dolomite.

Two methods have been used to estimate, from the contents of the samples, the quantity of anhydrite in each hundred feet of the section, from 2000 to 4095 feet below

the surface. One of these methods consisted in counting a convenient number of fragments of each kind of rock in each sample, and thus roughly determining the percentage of anhydrite. Some of the samples consist almost entirely of anhydrite, as from 2064 to 2068 feet, and from 3105 to 3110 feet below the surface. From 2200 to 2600 feet several samples consist largely of anhydrite, and there are such samples from 2700 to 3000 feet. Below 3110 feet the anhydrite content obtained by examining the cutting varies from 15 to 4 per cent, decreasing gradually downward. The percentage for all the samples between 2000 and 3000 feet is 25, and for the samples between 3000 and 4095 feet it is a little less than 10, making the average for the whole formation about 17 per cent.

Secondary Anhydrite

But these percentages do not represent the total contents of anhydrite in the formation; for in making the estimates by counting separate fragments, no account could be taken of the anhydrite occurring as microscopic crystals in the dolomite. A separate estimate was therefore made on the anhydrite included in dolomite, by roughly measuring the areas of anhydrite and dolomite in 186 thin sections prepared from cuttings of the dolomite. These cuttings were taken from 60 different depths, selected so as to represent each hundred feet in the section as nearly equally as practicable. Only 18 per cent of the thin sections were without anhydrite, and more than half of these were from the lowest 500 feet of the dolomite. The remaining 82 per cent of the sections contained from 1 to 60 per cent of anhydrite, apparently replacing part of the original sediment. Separate estimates were made for each 100 feet of the section, and account was made of the fact that each of these estimates represents only the anhydrite present in the percentages counted as dolomite in the previous estimates. These estimates show an additional 10 per cent for the whole section, 11 per cent for the upper oolitic and sandy dolomitic beds, and 8 per cent for the lower shaly dolomitic beds.

It is probable that these two estimates slightly overlap, that a few of the thin sections contain so much anhydrite that they might have been counted as anhydrite in making the first estimate. There is also an uncertainty as to the amount of shale present due to caving, and this prevents making a correction for the quantity of shale in each sample. The presence of caving shale would not affect the estimates, but the presence of shale belonging to the terranes would make the estimates too high. Taking this all into due consideration, it seems safe to conclude that the total anhydrite content is somewhere near 25 per cent for the whole formation; 35 per cent for the upper sandy and dolomitic beds from 2000 to 3000 feet below the surface; and 15 per cent for the lower shaly dolomitic beds between 3000 and 4095 feet below the surface. (See Plate 13.)

The following table of the two series of estimates for each hundred feet of rock will show the stratigraphic distribution of the anhydrite in greater detail:

TABLE

Showing estimates of contents of anhydrite in each hundred feet from 2000 to 4095 feet below the curb of the Spur boring

Part of section in feet below surface	Estimates based on ratios of fragments of anhydrite to fragments of other rocks in samples		Estimates based on ratios of anhydrite and dolomite in microscopic sections		Estimated total per cent of anhydrite
	No. of samples examined	Per cent of anhydrite	No of sections examined	Per cent of anhydrite	
2000–2099	4	19	3	6	25
2100–2199	2	12	1	26	38
2200–2299	9	12	13	6	18
2300–2399	6	35	3	13	48
2400–2499	3	60	1	Trace	60
2500–2599	2	50	5	4	54
2600–2699	11	10	30	18	28
2700–2799	3	40	12	10	50
2800–2899	----	30		12	42
2900–2999	5	20	17	18	38
3000–3099	14	15	8	14	29
3100–3199	19	15	15	13	28
3200–3299	19	15	11	2	17
3300–3399	19	12	8	2	20
3400–3499	20	11	9	12	23
3500–3599	18	8	6	3	11
3600–3699	20	7	13	20	27
3700–3799	9	... 7	6	14	21
3800–3899	9	7	10	8	15
3900–3999	8	4	9	1	5
4000–4095	14	4	7	2	6

Origin of the Anhydrite

That a part of the anhydrite in the sandy dolomite represents original beds of anhydrite cannot be doubted. The samples from 2331 to 2336, 2454 to 2460, 2476 to 2539, 2539 to 2606, contain little else than anhydrite. That much anhydrite in the whole section, and practically all below the depth of 3000 feet, is a secondary constituent, is equally clear. It occurs in crystalline form in small cavities in the dolomite throughout the formation. In some sections it is seen to replace parts of spherules in the oolites. (See Fig. 1 and Plate 2A.) Elsewhere it forms the matrix in which the oolitic spherules are imbedded. (Plate 8B.) In still other cases it forms the matrix and also fills the interior of spherules wholly or partly, and the crust of the spherule is alone composed of dolomite. Still other sections show a matrix of dolomite in which the emptied forms of the spherules have been filled with anhydrite. (Plate 8A.) In every case the introduced mineral shows relations to the oolitic structure of the rock, which it cannot have had originally. It is secondary in its present distribution. In one or two sections it appears to be collected into minute concretions. (Compare Plate 10A.) From near 2250 feet below the surface a piece of core was taken, which contained a concretion of anhydrite three inches in diameter and several concretions of smaller size. (See Plate 4.) The writer is inclined to the belief that much of the anhydrite has been formed in connection with the dolomitization of the limestone, as the result of a reaction between magnesium sulphate in circulating solutions and the calcium carbonate of the original sediment. This would explain the general diffusion of the anhydrite throughout the dolomite. Natural conditions have elsewhere caused anhydrite to be deposited in separate beds. Here we find 1000 feet, and more, of dolomite, which contain from 10 to 30 per cent of anhydrite in intimate mixture, almost everywhere. Another reason for believing conditions were different here is to be found in the fact that anhydrite ceases to appear in the

cuttings at the depth where the drill passed from dolomite into limestone.

OTHER MINERALS

Quartz

Quartz was noted in this rock in two forms. It occurs as chalcedonic quartz, mostly associated with concretions of anhydrite, which in some cases have an outer discontinuous and irregular layer of such quartz. Concretions of this kind were noted in cores coming from 2244 and from 2250 feet below the surface. (See Plate 4.) In the upper sample the concretions were from one-half to one inch in diameter, and in the lower from a half to nearly four inches. The largest of these concretions had such quartz also in irregular accumulations in its interior. Some very small concretions of quartz were noted in a piece of dolomite believed to have come from a depth of 1600 feet. A siliceous dolomite caused very slow drilling at the depth of 2214 to 2219 feet. In this rock the siliceous material is, at least in some of the rock, diffused in the dolomite, making this cherty. A gray chert of uniform texture made part of a core taken at from 2241 to 2271 feet below the surface. Clusters of straight microscopic bodies of quartz were noted in a sample taken at 2260 feet and again in a sample at from 2271 to 2329 feet. Drilling was very slow near these depths, and the chert must have been present in considerable quantity. But from this depth down to past 3900 feet, no more chert, flint or other secondary quartz appear in the cuttings. Some chert occurs at from 3965 to 3970 feet and at from 4030 to 4035 feet. At the latter depth it is light gray in color.

Calcite

Calcite is scarce throughout. Calcareous particles, effervescing promptly in acid, are usually lighter in color than the rock with which they come. They probably repre-

sent veins or concretionary segregated bodies of other forms. They were most frequently noted at 3180, 3230, 3350, 3365, 3420, 3430, 3540, 3590, and 3640 feet below the surface.

Pyrite

Much pyrite was reported by Mr. Minihan at from 2241 to 2271 feet, where it also appeared in the samples. Otherwise pyrite is rarely seen in this rock. It occurs as microscopic cubes in anhydrite at from 3205 to 3215 feet, and it was present in shale immediately above this depth. It was also noted at from 3350 to 3355 feet, from 3755 to 3760, and from 3935 to 3940 feet. There is no doubt of its presence in small quantities at many other depths, especially in dark shale and in dark dolomite that emit sulphurous fumes on heating.

Gypsum and Salt

Some small crystals of gypsum were noted in the sample from 2956 to 2980 feet, and the impure dolomite occurring between 2042 and 2047 feet contains some salt.

Bitumen and Ammonia

In many of the thin sections of dolomite, black, brownish, or yellowish streaks were noted, that evidently were not iron or manganese oxide. (Plate 12B.) On heating parts of some of these samples, and several others, in a closed tube, it was found that nearly all such rock yielded fumes of bituminous materials. In several cases, perceptible films or even minute drops of oil were obtained. Many samples also gave fumes of ammonia. Distillates of bituminous substances appear to be most frequent, and also most pronounced, at depths from 3000 to 3800 feet, while ammonia fumes appear to be most frequent from 3800 feet to the bottom of the dolomite. The two often occur together. The bituminous material is most common in dolomite, having been noted in shale in only one instance. Out of 35 samples

of rock heated in a closed tube, 27 gave bituminous fumes or both fumes and visible oil. Estimates based on the ascertained weight of minute quantities of oil obtained from a fourth of a grain of limestone indicated that the bituminous contents range from quantities too small to estimate, to one-tenth of a per cent of the weight of the rock.

Below is a list of the tests made, showing the results in each case. As no attempt was made to select the samples tested, they may be regarded as fairly representing the part of the formation from which they were taken, the mark * denoting the occurrence.

Depths.	Bituminous fumes noted in closed tube.	Visible oil noted in closed tube.	Fumes of ammonia noted in closed tube.
1250–2042	*		*
2250	*		
2241–2271			
2250–2264	*		
2260	*	*	
2392–2394	*		
2685–2698			
2698–2709	*	*	*
2987–3002	*		
3165–3170	*	*	
3185–3190	*	*	
3205–3210			
3285–3290	*	*	
3355–3360	*	*	
3470–3475	*		
3605–3610	*	*	*
3680–3685	*		
3690–3695	*		
3695–3700	*	*	
3700–3705	*	*	
3710–3715	*		
3735–3740	*		*
3755–3760	*		
3765–3770	*	*	*
3775–3780	*	*	*
3795–3800			*
3810–3815			*
3830–3840	*	*	*
3850–3855	*		*
3915–3920			*
3930–3935	*		*
3945–3950			*
3985–3990	*		*
4005–4010	*	*	*
4075–4080			*

THE CISCO FORMATION

Fragments of limestone first began to appear with the cuttings from 4100 to 4105 feet, and fragments of Fusulina appeared in the next sample below this, from 4110 to 4115 feet. After its first appearance, the limestone increased in quantity steadily in the returns for the next forty feet. Below 4150 feet the samples contained but little dolomite, consisting mostly of limestone and shale, down to the bottom of the well.

It is believed that the strata penetrated by the lowermost 394 feet of this boring are to be correlated with the upper part of the Cisco formation in the central part of the State. They consist of limestone and shale. Limestone is the chief rock from 4100 to 4400 feet, while the lowermost 89 feet are mostly shale.

Limestone

The limestone in the formation presents several varieties. In nearly all the sections examined, organic fragments are present as a notable ingredient. (Plate 12C.) One thin section is a granular crystalline limestone, in which the crystals are of two somewhat uniform sizes. The matrix consists of crystals from 0.01 to 0.02 mm. in diameter, and in this lie scattered bodies of clear calcite from 0.05 to 0.1 mm. in diameter. Most of the sections consist of a matrix composed of particles of calcite less than 0.01 mm. in diameter, and in this lie organic fragments and larger bodies of calcite up to the size of a half millimeter. Several instances were noted where the larger crystalline bodies of calcite were fillings in cavities having the outlines of organic fragments, such as pieces of shells or of stems of crinoids or spines of brachiopods. (Plate 12C.) In other instances, organic fragments were seen to have their internal structure preserved. At the depth of 4160 to 4165 feet, some of the limestone is oolitic. It is filled with oolitic spherules imbedded in a matrix having a texture like that of the other limestone, showing large variations in the size of the calcite

grains. Some oolitic spherules occur together with a multitude of organic fragments in the limestone from 4315 to 4320 feet. The sizes of the spherules in both these cases range mostly from 0.5 to 1.5 mm. in diameter. At from 4265 to 4270 feet occurs a brown limestone, which is rusty colored; however, only in spots. There is evidence here of alteration of the rock by the occurrence of calcite in cavities once filled by imbedded organic fragments.

In all of this limestone it is believed there are, here and there, some seams of shale. Below the depth of 4400 feet, limestone and shale appear to alternate to the bottom of the boring, the shale predominating. Much of the limestone in the lower 300 feet of the boring darkens when first heated in a flame, indicating the presence of organic material, as it again turns to a lighter color when ignited for a longer time.

Flint, or chert, is present in this limestone at several depths. White flint was noted at from 4130 to 4135 feet and from 4150 to 4155 feet. Bluish-white chert occurs at from 4205 to 4210, from 4250 to 4255, from 4260 to 4265, from 4275 to 4280, and from 4365 to 4370 feet.

Shale

The shale in the lowermost hundred feet is mostly very dark or black, and at some depths it contains pyrite, as at from 4400 to 4420 feet. Of eleven samples from this formation, three yielded oil and three more yielded perceptible fumes of bituminous distillates, when heated in a closed tube. Seven yielded fumes of ammonia. Most of these tests were made on samples of shale, but bituminous substance occurs also in some of the limestone. Shale yielding oil occurred at the depths from 4455 to 4460, 4480 to 4485, and from 4485 to 4489 feet. A light showing of gas was reported by the driller at near 4435 feet.

NOTES ON FOSSILS

For the purpose of making the record of this deep boring as complete as possible, all samples were examined for fossils. Only a few macroscopic fossils were seen. These were in a core taken between the depths of 2244 to 2264

feet. All other fossils were minute forms, found either in thin sections of dolomite and limestone or recovered by washing the triturated material in samples of cuttings taken by the drillers. Drawings have been made of a little more than a hundred individual specimens. These comprise several ostracods, some jaws of annelids, one or two brachiopods, one gastropod, several bryozoa, some sponge spicules, and a considerable number of foraminifera. Though foraminifera are, as a rule, of little importance for the identification of geological horizons, they are the principal material at hand in this case. It is thought that with a thorough study of the lithology and of the microscopic fossils in the Carboniferous and the Permian section in the State it will be possible eventually to definitely correlate all the parts of the section of this boring with the existing formations elsewhere.

Fossils in the Cisco

The principal fossil-bearing horizon is the Cisco, the lowermost 389 feet of the exploration. Fossils occur in the limestone as well as in the shale. Fusulina, Rhombopora, other bryozoa, and crinoid stems were noted most frequently in the limestone. Chitinous and other agglutinate foraminifera, jaws of annelids, and spicules of sponges were most frequent in the shales. A majority of these fossils are known from the Carboniferous in Europe and America, a few are known from the Permian, and some have probably not been reported from any other locality. A brief descriptive list, giving references to the respective drawings, is as below.

LIST OF FOSSILS FROM THE CISCO FORMATION

Several specimens of a shell resembling *Climacammina antiqua* Brady were noted. These were not very well preserved, and were more or less fragmentary. Two came from the sample taken between 4415 and 4420 feet, one from 4475 to 4480 feet, and one from 4485 to 4489 feet. The texture of the test could not be seen, but the labyrinthic intergrowths of the test into the chambers were evident, the

latter being filled with a perfectly opaque mineral. This form has been observed throughout the entire Carboniferous of England and Scotland, and it has been doubtfully noted in the Fusulina limestones of Russia. Figs. 4: a, c.

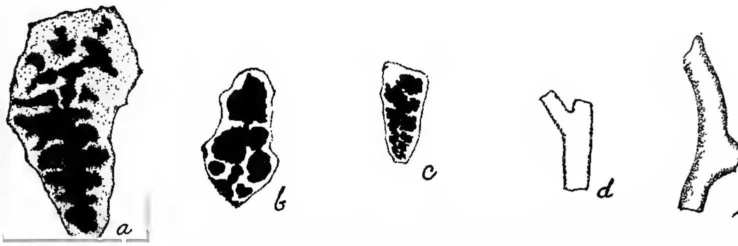

FIGURE 4. a, c, Climacammina antiqua Brady, from 4315–4320 feet below surface; b, unknown form, 4415–4420 and 4475–4480 feet; d, unknown form, 4485–4489 feet; e, unknown form, 4445–4450 and 4425–4430 feet. X 40.

Some very delicate, non-septate, and branching tubes were noted in the lowermost fifty feet of the well. Figure 4: d, e.

Forms which more or less resemble Nodosaria radicula, Nodosellina cylindrica, and Dentalina are common in the lowest two hundred feet of the Spur well. Some have the walls of the segments slightly bulging, in others the segments form tubes of uniform diameter. The segments are of variable length and diameter in most individuals. Some tests are perfectly straight, others show slight irregular bends. A protruding aperture is sometimes shown on the last segment. These forms are known from the Carboniferous and up. Figure 5: a—m.

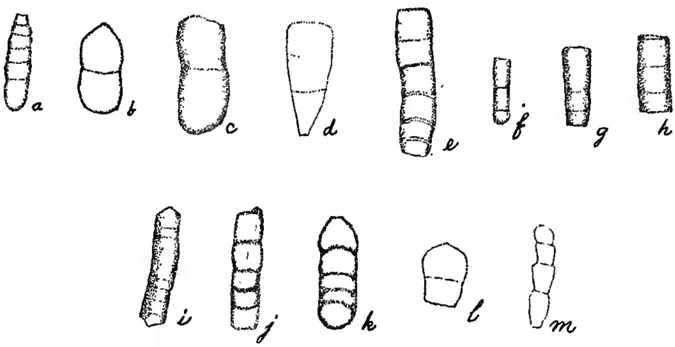

FIGURE 5. Unknown forms: a, 4455–4460 feet below surface; b, 4367–4370 feet, 4315–4320 feet; c, 4455–4460 feet; d, 4425–4430; e, 4445–4450 feet; f, 4455–4460 feet; g, 4385–4390 feet, 4405–4410 feet; h, 4405–4410 feet; i, 4285–4290, 4425–4430 feet; j, 4285–4290, 4405–4410 feet; k, 4485–4489 feet; l, 4445–4450 feet. X 40.

In the lowermost hundred feet were some minute fusiform fragments of fossils which have a resemblance in outline to Saccammina and Lagena, also known from the Carboniferous. Figure 6: a—e.

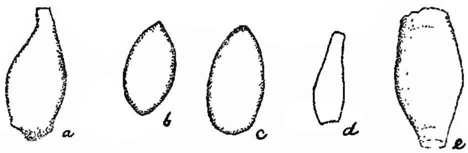

FIGURE 6. a, Lagena (?), 4445–4450 feet below surface; b, Saccammina (?), 4385–4390, 4405–4410, 4415–4420, 4435–4440, 4465–4470, 4480–4485, 4485–4489 feet; c, Lagena (?), 4485–4489 feet; d, Lagena (?), 4415–4420 feet. X 40.

There are a number of delicate tubular organisms, of apparently homogeneous texture, which resemble in form Trochammina gordialis and incerta, figured by Brady. The shell is sometimes of ferruginous color, but also colorless. All are more or less chitinous. Most of the forms are small. Figure 7: a—h.

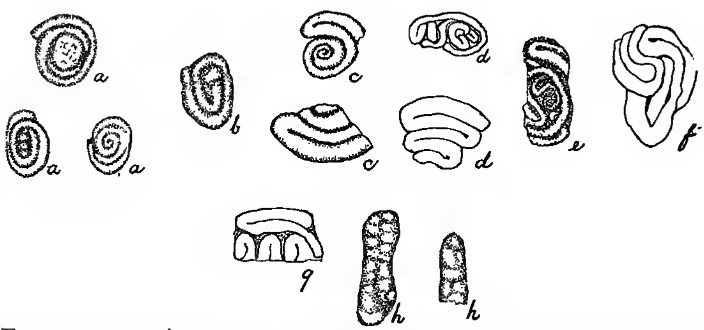

FIGURE 7. Trochammina incerta d'Orbigny, a, 4305–4310, 4475–4480 feet below surface; b, 4385–4390 feet; Trochammina gordialis Jones and Parker, c, 4395–4400, 4405–4410 feet; d, 4425–4430, 4445–4450, 4455–4460, 4465–4470, 4475–4480, 4485–4490; e, 4405–4410, 4425–4430, 4445–4450 feet; f, 4395–4400, 4405–4410, 4415–4420, 4425–4430 feet; g, 4480–4485 feet; h, 4415–4420, 4425–4430, feet. X 40.

Flat spirally-coiled tubes of chitinous material were noted at from 4150 feet to the bottom of the well. These resemble the genus Ammodiscus. In the diameter of the tube they differ considerably, and also in the number of coils. In some the inner whorls are of about the same diameter as the outer, and at the center is usually seen a chamber, which often has a wider diameter than the tube. Where the inner whorls are very small no such chamber is seen.

The discs range from 0.1 to 0.3 mm. in diameter. Figure 8: a, b, c.

Several tests were noted which had an exterior resemblance to Valvulina bulloides as figured by Brady. These consisted of one large segment having one or several smaller segments attached on one side. It is quite probable that they are irregular forms of Endothyra. Figure 8: d, e, f.

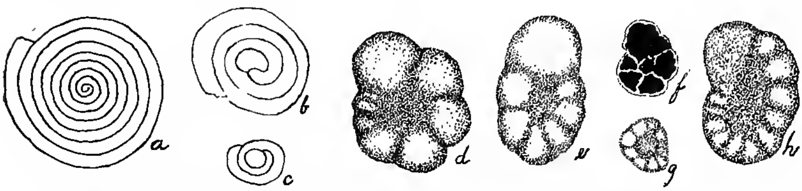

FIGURE 8. Ammodiscus sp., a, 3755, 3775, 3795, 3820, 4150, 4260, 4275, 4300, 4330, 4340, 4360, 4365, 4375, 4400, 4420, 4430, 4450, 4460 feet below surface; b, 4275–4280, 4330–4335, 4340–4345, 4360–4365, 4365–4370, 4375–4380, 4385–4390 feet; Valvulina bulloides Brady; d, 4395–4400 feet; f, 4415–4420, 4405–4410 feet; g, Endothyra bowmani Phillips, 4340–4345. 4350–4355, 4360–4365, 4365–4370, 4375–4380, 4385–4390, 4405–4410, 4415–4420, 4425–4430, 4445–4450 feet; h, 4380–4385, 4385–4390, 4480–4485 feet. X 40.

Some more or less disc-shaped or cone-shaped tests with an uneven exterior surface showed dim oblique lines indicating boundaries of segments arranged somewhat as in Valvulina rudis Brady. The specimens seen had the interior more or less filled with an opaque mineral. This species has been noted by Brady from the fusulina-bearing Carboniferous in Iowa. Figure 9: a, b, c.

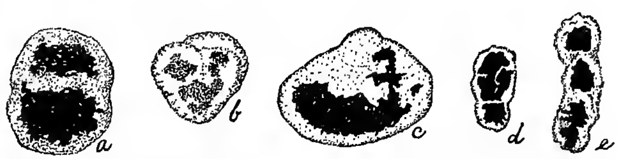

FIGURE 9. Valvulina rudis Brady, a, 4465–4470 feet below surface; b, 4475–4480 feet; c, 4475–4480 feet; unknown, d, e, 4385–4390, 4395–4400 feet. X 40.

Discs with a central circular area are not rare, varying from 1 to 3 mm. in diameter. One had a cross in the central circle like the outline of the last chambers in Valvulina palaeotrochus. Some of these discs are probably detached segments of cylindric forms of various foraminifera. Figure 10: e, f.

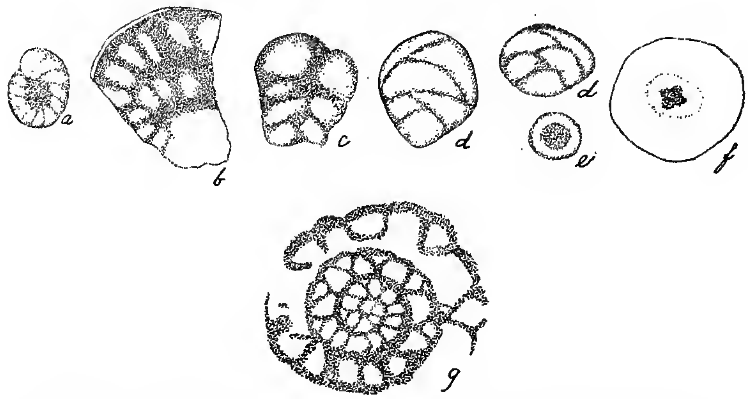

FIGURE 10. Endothyra sp., a, 4445–4450, 4455–4460 feet below surface; b, 4315–4320, 4425–4430 feet; Textularia (?), c, 4265–4270 feet; Textularia (?), d, 4415–4420, 4445–4450, 4455–4460, 4475–4480 feet; unknown, e, 4250–4255, 4275–4280, 4340–4345, 4385–4390 feet; f, 4465–4470 feet; g, Fusulina cylindrica, occurs frequently from 4115 to 4350 feet (cross section, X 50). X 40.

A few segmented structures with a rough exterior and a thick and irregular wall were noted at the depths 4385 to 4400 feet below the surface. The interior is filled with an opaque mineral and the interruptions in this filling mark the segments more than the external form. The organisms were evidently free. Stacheia? Figure 9: d, e.

Some forms quite like Nodosaria are laterally unsymmetrical, and have one side straight and the other convex. These may be halves of Textularia Jonesi Brady, which is known from the Kupferschiefer in Germany and in the Upper Magnesian limestone in England, both Permian. These were noted in the lowermost 115 feet of the well. Figure 11: e, f, g, h.

One of the most common foraminifers in the lowest 400 feet penetrated by the Spur well is a flat arrowhead-shaped test, from less than ⅛ to more than ¼ mm. in length. It consists of a primordial spherical chamber, on one side of which adhere a series of later chambers of successively larger size. The increase in size of successive chambers is variable, decreasing in the two or three last ones, the last chamber sometimes being smaller than the one next preceding. Interiorly, the chambers are smooth. The septal lines are concave toward the primordial chamber. In the progressive widening of successive chambers there is much variation. In some specimens the increase in size is small, while in others it causes the lateral outlines to diverge fifty degrees. The aperture was not seen, but a dim median structure was noted in one instance. The fact that only one side is filled by an opaque mineral in some chambers

in another specimen indicates the presence of some median structure preventing the completion of the filling. The depth of the chambers varies from one-half to one-fifth of their width. Forms like these were noted in most samples below 4195 feet. This form is more common than any other foraminifer noted. Figure 11: a, á, a″, b, c, d, d'. The test resembles Geinitzia post-carbonica Erich Spandel in some respects.

A well-preserved fragment, very gently tapering, broken at both ends, with the form of segments figured by Geinitz from a drawing by von Reuss of Textularia multilocularis from the Lower Zechstein, was noted in the sample from 4480 to 4485 feet. Figure 11: i.

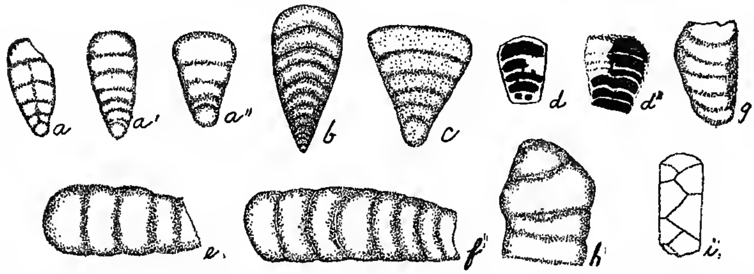

FIGURE 11. Nodosaria (?) a, 4225–4280, 4295–4300, 4305–4310, 4330–4335, 4360–4365, 4375–4380, 4385–4390, 4405–4410, 4415–4420, 4425–4430, 4445–4450, 4480–4485 feet; b, 4375–4380, 4385–4390, 4405–4410 (several), 4415–4420 (several), 4465–4470, 4480–4485, 4485–4489 feet; c, 4360–4365, 4375–4380, 4405–4410, 4435–4440, 4445–4450 feet; d, 4195–4200; 4365–4370, 4385–4390, 4455–4460 feet; Textularia Jonesi Brady (?) e, 4275–4280, 4385–4390, 4395–4400, 4425–4430, 4445–4450 feet; f, 4480–4485 feet; g, 4375–4380, 4445–4450 feet; h, 4455–4460 feet. X 40.

A single individual test noted at 4270 feet below the surface, consisted of segments biserially arranged as in Bigenerina or Textularia. Figure 10: c.

In the lowest 100 feet of the well a test was noted having segments biserially arranged increasing rapidly in size and overlapping each other far. The external surface was smooth and the septal lines distinctly marked. It had the appearance of a hyaline test. Textularia, sp.? Figure 10: d.

Some tests, which no doubt are an Endothyra, have the segments more numerous than they are in Endothyra jonesi, and the sutures extend obliquely inward, from the periphery. They may, perhaps, be referred to E. globulus Brady. Figure 10: a, b.

Tests of the form of Endothyra bowmani were noted from the depth of 4340 to 4450 feet below the surface. This is known from both the Lower and the Upper Carboniferous. Figure 8: g, h.

Fusulina was noted in fourteen samples as follows: 4115, 4135, 4155, 4165, 4175, 4185, 4190, 4210, 4220, 4230, 4325, 4350. In the central part of Texas Fusulina has not been reported from higher up than the Cisco. Figure 10: g.

Spicules of sponges are common. Dimeres, tetrameres, pentameres and hexameres were noted. The dimeres occurred in two forms, one with blunt and one with sharp points. The tubular axial cavity in the spicules was noted in several cases. These fossils evidently represent the Dictyospongidae. Figure 12: a—h.

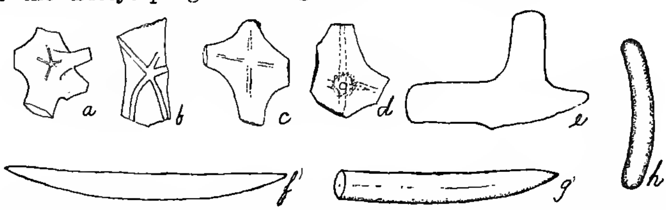

FIGURE 12. Pentamere sponge spicules, a, 4415–4420 feet below surface; b, 4320–4325 feet; tetramere, c, 4275–4280 feet; hexamere (?), d, 4305–4310 feet; tetramere, e, 4425–4430 feet; dimeres, f, 4320–4325 feet; g, 4250–4255 feet; h, 4195–4200, 4215–4220, 4225–4230, 4275–4280, 4285–4290, 4330–4335, 4365–4370, 4385–4390, 4415–4420, 4445–4450, 4455–4460, 4475–4480 feet. X 40.

Pinnules and spines of crinoids and especially joints of the stems of crinoids are often present in the Cisco. The pinnules are grooved on one side. An unusual form is shown in Figure 13: f.

A fluted and tuberculated spine of an echinoid was noted at 4485 feet. Archeocidaris?

Rhombopora lepidodenroides was noted at 4165 and 4275 feet, and between these points, but seldom below. Other bryozoa were scarce but not absent. One is represented in Figure 13: d, another in Figure 13: e.

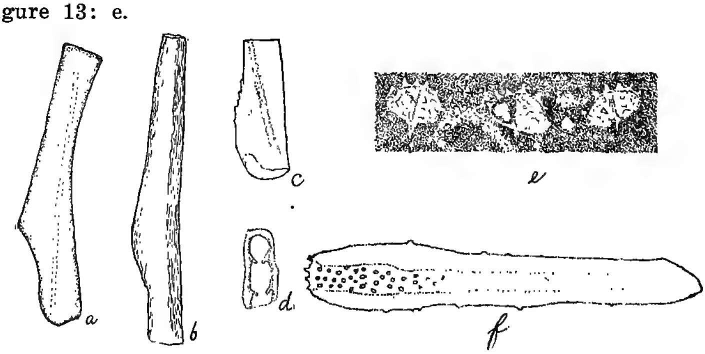

FIGURE 13. Jaws of annelids,* a, 4445–4450 feet below surface; b, 4385–4390 feet; c, 4225–4230, 4295–4300; 4365–4370 feet; d, unidentified bryozoan, 4425–4430 feet; e, ditto, seen in a thin section in limestone, in cross section, 4140–4145 feet; f, pinnule of crinoid (?), 4465–4470 feet. X 40.

*These are now known as conodonts.

Ambocoelia planoconvexa is believed to have been represented in the two next to the deepest samples. Two very young specimens of a brachiopod of this type were noted. One of these is shown in Figure 14: a, in imperfect rough outline.

A valve of a shell of unknown affinities was seen in the next to the last sample in the well. It is shown in Figure 14: i.

Broken parts of chitinous jaws resembling forms ascribed to annelids were noted in a few samples. Three of these are probably referable to one and the same species, differing only slightly in

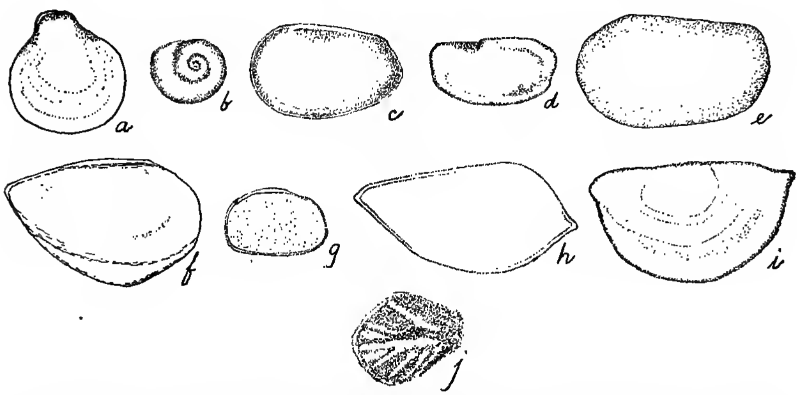

FIGURE 14. Ambocoelia planoconvexa (?), a, 4475–4480, 4480–4485 feet below surface; b, apex of gastropod, 4395–4400 feet. Similar apexes noted at 4275–4280, 4415–4420, 4465–4470, 4480–4485, 4470–4475, 4485–4489 feet; c, ostracods, 4275–4280, 4445–4450 feet; d, 4385–4390 feet; e, 4435–4440 feet; f, 4415–4420, 4435–4440 feet; g, 4465–4470, 4475–4480 feet; h, 4265–4270, 4375–4380, 4425–4430, 4465–4470, 4475–4480 feet; i, affinity obscure, 4480–4485 feet; j, fish scale (?), 4365–4370 feet. X 20.

form. All were fragments. Figure 13: a, b, c.

Apexes of gastropods were noted in eight samples, one at 4280 feet, and the rest all below 4400 feet. One is shown in Figure 14: b.

Ostracods occur in the samples from 4265 to 4480 feet below the surface. All the individuals being small and probably young and seen but from one side, their identification is uncertain and could be made only from the general outlines of the specimens seen. Aparchites humerosus, Bairdia beedei, and Jonesina bolliaformis appear to be represented. The forms named are known in the Permo-Carboniferous of Kansas and in the Carboniferous and Permian of Texas. Figure 14: c—h.

An organic fragment which bears some resemblance to a fish scale was seen at the depth of 4370 feet. It was of material having a yellowish color. Figure 14: j.

Fossils in the Shaly Dolomite Beds

A few fossils were noted at scattered intervals in the samples coming from the shaly dolomite beds. Some seem to come from the shale, which is interbedded in the dolomite. Ammodiscus, a flat spiral form, frequently noted in the Cisco, was found at from 3755 to 3760, 3775 to 3780, 3795 to 3800, and from 3900 to 3905 feet. (Fig. 15: a.) Sponge spicules were also noted in several thin sections of the dolomite. Undoubted specimens of sponge spicules were noted below 3800 feet in several samples, evidently having come from shale. In a fragment of limestone from 3185 to 3190 feet there was a section of some bivalve, much fractured. (Fig. 15:f.)

Fossils from the Sandy Dolomite Beds

From 2677 to 2956 Feet

In thin sections of dolomite coming from 2677 to 2682 feet, and again from 2709 to 2735 feet below the surface, a form like a Nodosaria was noted. (Fig. 15:b, c, d.) In another section of dolomite from between 2950 to 2956 feet appears a fossil which perhaps is a tangential section of the shell of a ribbed brachiopod, near its beak. (Fig. 15:e.)

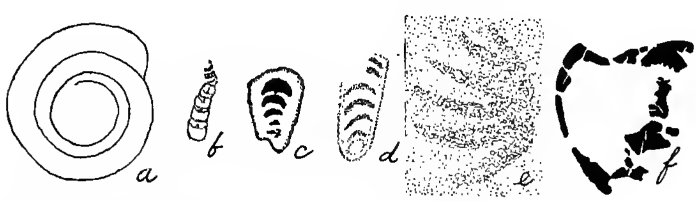

FIGURE 15. Ammodiscus, sp., a, 3755–3760, 3775–3780, 3795–3800, 3900–3905 feet below surface; b, 2677–2682, 2709–2735 feet; c, 2709–2735 feet; d, 2709–2735 feet; e, 2950–2956 feet; f, 3185–3190 feet; a-d, X 40 e-f, X 20.

From 2244 to 2264 Feet

In the core of mostly oolitic dolomite taken at this depth, the following fossils were seen either in thin sections or macroscopically.

a. Seen in thin sections.

1. Cellular tissue in a shred of bituminous yellow material imbedded in dolomite. Figure 16: b. In the same section were many smaller shreds of structureless yellow or brown material of similar nature and also two round bodies resembling spores. Figure 16: a, c.

2. Trochammina sp.? Figure 16: e.

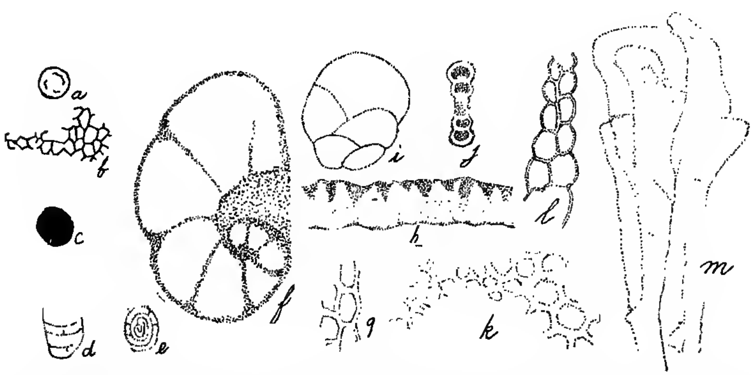

FIGURE 16. Fossils seen in thin sections made from a core taken from between 2244 and 2264 feet below the surface. a-k, m, X 40; l, X 25.

3. Cross section of the disk of a flat spiral foraminifer. Ammodiscus? Figure 16: j.

4. Outline, in oblique aspect, of a foraminifer with biserially arranged chambers. Figure 16: i.

5. Section of an Endothyra, parallel with disc. Figure 16: f.

6. Outlines of some chambers of a Nodosaria. Figure 16: d.

7. Bryozoa, several forms, seen from various angles. Figure 16: g, h, k, l, m.

b. Seen macroscopically.

8. Fragment of a brachiopod.

9. A small part of the zoarium of a Fenestella, showing eight fenestrules, appears on the polished surface of a piece from the core. There are two branches in one mm. and about five dissepiments in two mm. A double row of zoëcia was seen on each branch, four pairs in the distance of one fenestrule, with one dissepiment.

10. A small part of the surface of one bryozoan shows very minute pores of sub-equal size, about one-thirtieth mm. in diameter. They are vertical terminations of zoëcia. The extent of the surface is about two square millimeters.

11. The three first whorls of a small flat-coiled shell, probably a Euomphalus. Its outer whorl measures less than two mm. across.

12. Parts of the valves of a small pelecypod. It measured less than two mm. in length, and had delicate lines of growth on the outer surface of the shell. It may have been a small Edmondia.

From 1250 to 2042 Feet

Another piece of core of oolitic dolomite was taken somewhere between 1250 and 2042 feet below the surface, hence at least two hundred feet higher up in the column than the horizon from which the preceding fossils were taken. The smaller of these fragmentary fossils are incrusted, like oolitic spherules. These fossils are all from one and the same depth, wherever this be, within the limits known. The list is as follows:

1. Trochammina gordialis. Figure 17: b.
2. Nodosaria, sp. Figure 17: a.
3. A piece of a perforate form like Lituola bennieana Brady. Figure 17: d.

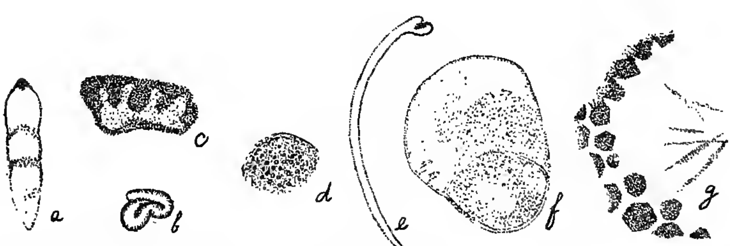

FIGURE 17. Fossils from a piece of core somewhere between 1250 and 2040 feet below the surface. Seen in thin sections of oolitic dolomite. X 40.

4. Various parts of bryozoa, resembling those taken at from 2244 to 2264 feet below the surface. Figure 17: c, g.
5. Oblique section of some small gastropod. Figure 17: f.
6. Vertical cross section of the valve of some ostracod. Figure 17: e.

ECONOMIC RESULTS

Water

This boring emphasizes the fact, long known, that water is very scarce in the Pennsylvanian and the Permian sediments on the plains of the Southwest, and also that most of the water they contain is too salty for use. The sandstone from 400 to 450 feet was so dry that casing had to be set to retain the water necessary for drilling. A small seep of water was noted near 2050 feet below the surface, but this was so small that when later the water was bailed down to 2300 feet, it filled up only 160 feet, over night. The well was then cased down to 1360 feet. Two other small seeps of water are reported by Mr. Minihan, one between 2980 and 2995 feet, and another near 4260 feet below the surface. The experience in regard to water has been the same in other deep wells on the Plains from Childress to Upland. The chances are that, if any deep potable water will ever be found in the Red Bed area, it will come from below the Pennsylvanian, and perhaps below the entire Carboniferous, at some depth exceeding 5000 feet. There can be little doubt that there are at least several hundred, and probably more than a thousand feet more of Pennsylvanian strata under the bottom of this boring. The existence of such deep water is highly improbable.

Discovery of Potash

What may eventually be the most important economic result of this boring is that it has proved the existence in

the dolomite beds of a stratum, or horizon, from which comes a water sufficiently rich in potash to hold out inducement to prospective search for this mineral.

The presence of much anhydrite and salt in the uppermost 1200 feet, in the section of the boring, caused the writer to suggest that an analysis of the water in the well be made to determine its potash content. At the time this suggestion was made, the hole had already been cased to below 1300 feet, and all water from strata above this depth had been shut off.

A sample of water was taken on April 12, 1912, after the water had been bailed out down to 2200 feet below the surface. This water was analyzed a week later by S. H. Worrell, Chemist of the Bureau of Economic Geology and Technology of the University of Texas. His analysis showed the following mineral ingredients present in the quantities stated:

	Grains per U. S. Gal.
Calcium sulphate	1,406.19
Calcium chloride	679.02
Magnesium chloride	219.20
Sodium chloride	3,410.55
Potassium chloride	324.14
	6,039.10

In other words, the potassium chloride amounted to five grams per liter, and constituted 5.4 per cent of all solids. This being an unusually high content of potash in natural water, arrangements were later made for taking samples of water from different depths below the bottom of the 1350-foot casing. In June, of the same year, 14 such samples were obtained and later tested for potash. The depths at which these samples were taken and the determined contents of potash in each are as in the table below, in which the April sample is included also.

Potash content of fifteen samples of water taken at different depths in S. M. Swenson & Sons' deep boring at Spur, Texas:

	A		B.	C.	D.	E.
1.	800		800	72.2	.5	?
2.	1,360		300	59.1	.3	?
3.	1,390		1,390	61.9	.4	?
4.	1,500	(Drip water)	1,550	21.4	.4	?
5.	1,600		1,600	42.9	.2	71
6.	1,800		1,390	94.4	.4	?
7.	1,830		1,830	47.2	.2	?
8.	2,000		2,000	41.0	.2	?
9.	2,200	(April sample)	2,200	324.1	5.4	?
10.	2,200		1,500	113.3	.5	71
11.	2,300		2,300	60.2	.3	74
12.	2,400		2,400	69.6	.4	74
13.	2,600		1,500	86.2	.4	71
14.	2,690		2,400	29.1	.2	75
15.	3,000		1,500	43.6	.2	73

A—Depth at which sample was taken, in feet below surface.
B—Depth to surface of water when sample was taken, in feet below surface.
C—Grains of potassium chloride per U. S. gallon.
D—Per cent of potassium chloride to total solids.
E—Temperature of sample when taken, Fahr.

Some of the samples were taken before much water had been bailed out of the well, while other samples were taken at intervals as the water was being bailed out. The table shows these particulars of the sampling, and it also gives some data on temperatures of the water samples when coming out of the well. The fact that the samples from 2200, 2600 and 3000 feet below the surface, bailed out when the water was standing at 1500 feet below the surface, had in each case a lower temperature than the samples taken at 2690, 2400 and 2300, when the water was standing at considerably lower depths, respectively, 2600, 2400 and 2300 feet below the surface, shows conclusively that the water from the different depths in the well had been mixed by convection currents caused by differences in temperature in the upper and the lower part of the hole. Each one of these analyses hence shows the potash content of a sample of water containing a mixture of all soluble sub-

stances present anywhere in the wall of the well. It is not at all likely that the potash is uniformly distributed in this section of sediments 2650 feet thick. On the contrary, it can be taken for granted that the mineral is confined to one or, at most, to a few distinct beds produced at times favorable to the precipitation of this mineral in the sea in which the sediments formed, or introduced by ground water at some later time.

As the convection of the water in the well is slow, owing to the small size of the hole and the slight difference between bottom and top temperatures, it is to be inferred that an ingredient in the solution supplied at a certain level would be present near that depth in greater quantity than at any other depth.

The differences in the analyses made hence indicate the presence of a potash-bearing stratum somewhere near 2200 feet below the surface in this well. The sample having 324.1 grains per U. S. gallon was taken when work on the well ceased for a while, in April, 1912. All the other samples were taken two months later, before the work of drilling was resumed. The water had then been standing undisturbed for two months, and the potash-bearing ingredient in the entire seepage had evidently been more evenly distributed through all the water in the hole. The maximum quantity of potash, in the 14 samples taken in June, is only one-third the quantity in the sample taken in April. It has been suggested that the general tendency of potash to diffuse by capillarity might readily account for the lesser amount present at 2200 feet after the well had been left undisturbed for two months. The potash would tend to "soak" into the walls of the hole, and be thus extracted from the solution by capillary filtration. But we still find the greatest quantity of potash (113.3 grains) at the depth where the first sample was taken containing 324 grains per U. S. gallon. It is also quite significant that the sample showing the smallest quantity of potash was the only sample not really a mixture of all the water in the well. This was taken by suspending the bucket at 1500 feet when the water had been bailed down to 1550 feet. It consisted

of water dripping from the wall of the hole and probably was a mixture of spilled water adhering to the wall of the well, and of some water trickling out from the rock above the depths where the bailer was hung, below the base of the casing. This sample contained only 21.4 grains of potash per gallon.*

Analyses of Rock Samples

Wishing to verify, if possible, the evidence from the water analyses, a number of tests for potash were made on the rock samples. It was evident that the chances for finding the original potash in the rock samples was very small, for two reasons. In the first place, the samples taken at the indicated levels were few and were selected to represent the principal kind of rock. Only one single sample was taken to represent all the material penetrated from 2128 to 2212 feet. This was a brown sandy clay. Should this bed contain the potash, it would most likely be confined to a few feet of the deposit rather than be present in the whole stratum. The sample taken from this bed consisted of fairly large cuttings and no doubt really represented but a few feet of the whole bed. Another sample represents 42 feet of rock, of nearly the same kind, from 2068 to 2110 feet. In the second place, from the finer particles, which might represent different depths within a greater thickness, any potash originally present could hardly have escaped being dissolved while in the circulating water carrying the returns, and most potash might have been lost in the same way from the entire sample, in each case. A number of samples were tested from the salt-bearing strata in the upper part of the hole. These served as a check on the lower samples. It may be worth the while to note that the samples from 2000 to 2300 feet were taken during the time from May to September, 1911. There was then no thought

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*The above account of the writer's observations on potash are taken, with slight changes, from his article on "Potash in the Permian of Texas," published in the *American Fertilizer* for December, 1912.

of looking for potash. The first test for potash in the water was made in April of the following year. The analyses of the rock samples from 732 to 1250 feet were made in February, 1914. All analyses were made by the Chemist of the Bureau, Mr. S. H. Worrell. The results are given below:

TESTS FOR POTASH IN CUTTINGS AND PIECES OF CORE FROM THE SPUR BORING

Depth of samples in feet below surface. From	To		Potash.
732	741	(cuttings)	0
914	931	(core)	0
931	932	(core)	0
958	962	(core)	0
962	1113	(core)	0
1113	1117	(core)	0
1117	1123	(core)	0
1174	1222	(cuttings)	0
1222	1235	(core)	0
1235	1250	(core)	0
	Near 2000	(cuttings)	0
2000	2200	(cuttings)	0
2042	2047	(cuttings)	Trace
2047	2049	(cuttings)	0
2049	2063	(cuttings)	0
2064	2068	(cuttings)	0
2068	2110	(cuttings)	Pronounced trace
2110	2126	(cuttings)	0
2128	2212	(cuttings)	0
2212	2214	(cuttings)	0
2214	2219	(cuttings)	0
2219	2241	(cuttings)	0
2244	2264	(core)	0
2271	2329	(cuttings)	0
2329	2331	(cuttings)	0
2331	2336	(cuttings)	0
2336	2338	(cuttings)	0
2392	2394	(cuttings)	0

It can hardly be a mere coincidence that traces of potash were found in the solid rock only near the level where the potash content was highest in the well water. The very

unusual amount of 324 grains per gallon also strongly suggests the existence of more than a mere slight impregnation in some stratum. Even after the potash had dissolved from the exposed walls of this stratum and had been diluted through a column of water three thousand feet high, it was present in an amount averaging 60 grains per gallon for all the water tested. It is to be recalled that salt was present in some rock samples, evidently as an original ingredient, from 1600 feet, and again from 2244 to 2264 feet below the surface.

Prospecting for Potash.

Considering the great value of a workable deposit of potash, it seems worth the while to call attention to another circumstance in connection with these observations. In either direction north or south from Spur the formations lie practically horizontal for at least a hundred miles, and the potash-bearing horizon, whether it be such or not in other places, must be at about the same depth as here, in these directions. It seems to the writer that the general conditions indicated in this boring, the existence of great salt beds and beds of anhydrite, together with the proven potash-bearing stratum, warrants an examination for potash in water from the same horizon in any boring made in this territory.

Westward Dip of Strata

East or west from Spur the depth to this horizon will be greater westward and less eastward. The elevation of the railroad depot at Spur is 2274 feet above sea-level. This is 666 feet higher than the elevation at Cisco, about 120 miles to the east-southeast. A line connecting these two points may be taken to follow the direction of the general dip of the formations to the west. The bottom of the well may be taken to represent the beds outcropping at Cisco. On this assumption, the general dip between Cisco and Spur, a distance of 120 miles, will be equal to the depth of the Spur

well, less the difference in elevation of the two places. This gives us a dip to the west of nearly 32 feet per mile. Our inability to fix the precise level in the Cisco formation reached in the boring may make this figure either a little too high or too low, but it cannot be far from right. Taking into consideration the general east slope of the land surface, which averages 6 feet per mile, any stratum should come nearer the surface at the rate of 38 feet per mile eastward from Spur.

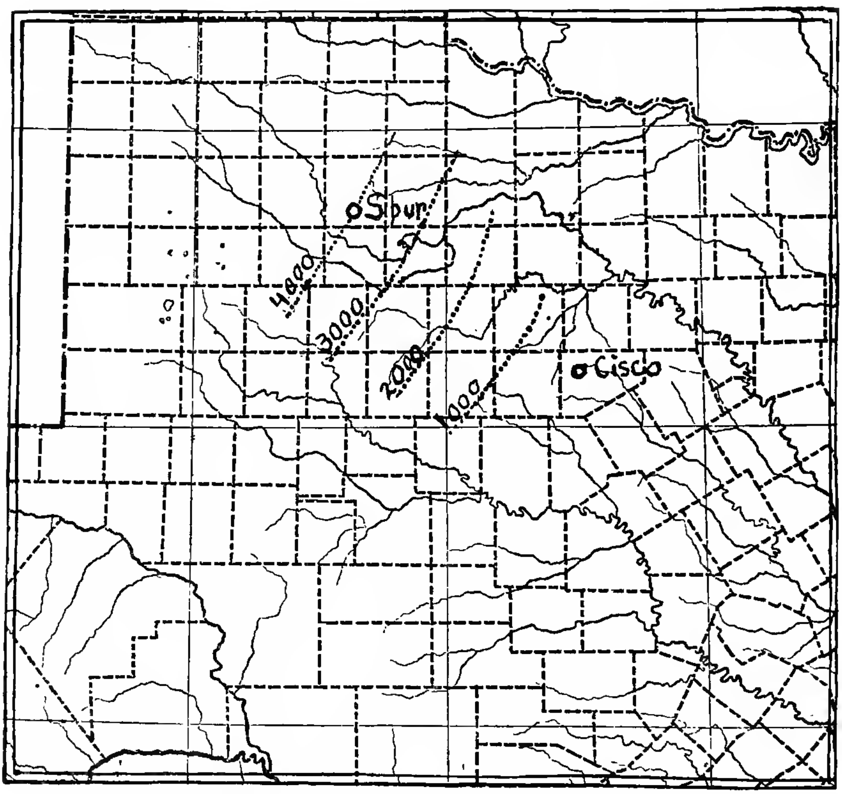

FIGURE 18. Sketch map of a part of Texas, with contours showing the probable approximate depth, in feet below surface, to the Cisco formation, in the country between Cisco and Spur.

Outcrop of the Potash-bearing Horizon

Assuming now that this general dip is constant between the two points, and that the formations are continuous, the horizon which yielded potash in the Spur well should outcrop in a belt where the land surface intersects the dipping plane lying 2200 feet below the surface at Spur. This belt would extend through Haskell and Jones counties. It is not to be expected that potash should be found in any outcropping rock in this belt, owing to surface leaching, but well waters there might show its former existence. Dr. Harper and Dr. Bailey of the School of Chemistry in the University of Texas have analyzed a number of water samples from wells near Haskell, and they have informed the writer that some of these waters contain an unusually large quantity of nitrate, which is not believed to be derived from the surface. It is suspected that this nitrate exists in the form of a potassium compound, as saltpeter. Along the line of the Kansas City & Orient Railroad in these counties the potash-bearing horizon may be looked for at depths of from 100 to 400 feet.

Potash in Other Well-waters in Texas

For making a comparison between the Spur well-water and other well-waters in the Pennsylvanian and Permian formations of the north and central parts of Texas, the records of water analyses made by the School of Chemistry in the University of Texas have been examined. Seventeen analyses were found in which determination of potash have been made. All these have less than 8 grains per gallon, and average 2.16 grains per gallon. The records do not show what waters these were, in all cases, but they are all believed to have been well-waters.

Table Showing Potash Contents in Seventeen Samples of (Well?) Water from the Pennsylvanian and the Permian in the Northwest and Central Parts of Texas

		Potash in grains per U. S. gallon
1.	Weatherford, Parker County, well 215 feet deep	.09
2.	Haskell, Haskell County	.30
3.	Weatherford, Parker County, well 1425 feet deep	.33
4.	Arlington, Tarrant County	.52
5.	Weatherford, Parker County	.61
6.	Rochelle, McCulloch County	1.11
7.	Mineral Wells, Palo Pinto County	1.21
8.	Mangum, Eastland County	1.22
9.	Burleson, Johnson County	1.39
10.	Fort Worth, Tarrant County	1.40
11.	Crazy Well No. 2, Mineral Wells, Palo Pinto County	2.45
12.	Mineral Wells, Palo Pinto County	2.55
13.	Thurber, Erath County	3.20
14.	Lampasas, Lampasas County	4.34
15.	De Leon, Comanche County	6.67
16.	Mineral Wells, Palo Pinto County	7.52
17.	Crazy Well No. 2, Mineral Wells, Palo Pinto County	8.03

OIL AND GAS

It has been shown that the dolomite from 1500 feet to 4100 feet below the surface frequently contains bituminous material. The driller reported a slight showing of gas near 4435 feet. It is believed that there are sufficient bitumens in these formations to have formed workable quantities, if the strata were such as to permit the oil and gas to accumulate in favorable structures. The Clear Fork beds are known to be bituminous in their outcrops. From the tests made on the bituminous contents of 27 samples of the rock, it is believed that it is safe to assume that

the rocks examined contained a minimum of one-twentieth of a per cent of bitumens. This would be sufficient to make a layer a foot thick from 2000 feet of rock. The rocks of the dolomite beds, and still more the rocks of the Cisco, must be regarded as sufficiently bituminous to produce large accumulations of oil and gas under favorable structural and lithological conditions. But the fact that the entire column of formations explored in the well below the Red Beds consist of compact sediments that do not even yield salt water, shows that the rocks are not in this locality sufficiently porous to have permitted the accumulation of any fluids they may have contained. The dolomite is compact and the sandstones are fine-grained, having their interstices filled with red clay. Everything considered, the prospect for oil or gas in this vicinity must be regarded as decidedly discouraging, for the depth to which the exploration extends.

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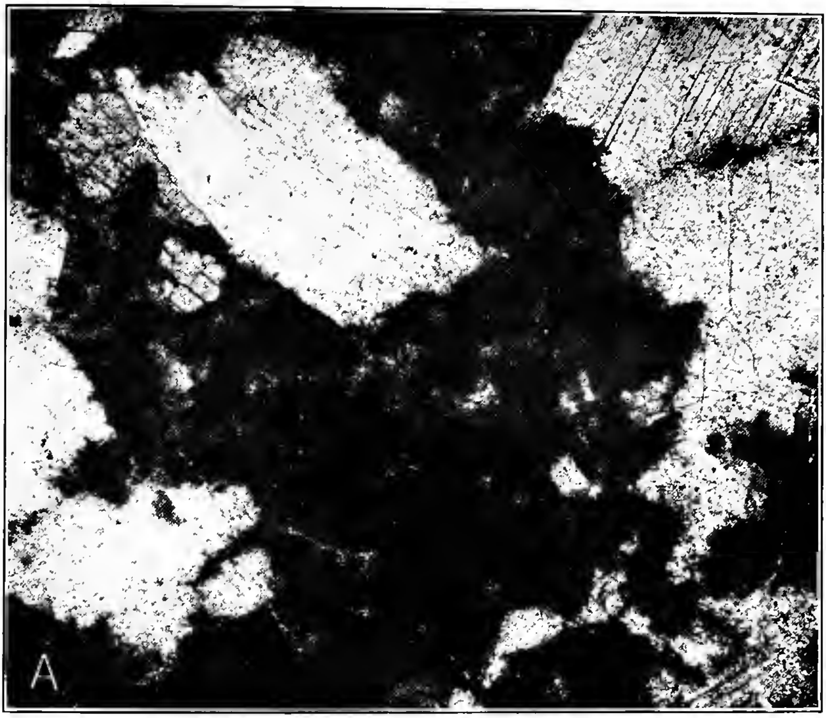


PLATE 1. A. Thin section of oolitic dolomite from somewhere between 1250 and 2042 feet below the surface. The spherules are closely appressed and the matrix in which they are imbedded is scant. It is seen in dim light lines. Much of the oolitic rock has been replaced by anhydrite, which appears as light striated tracts in the section. This is one phase of the rock described under number 74 (4) in the descriptions of well samples. Vertical section. X 40.

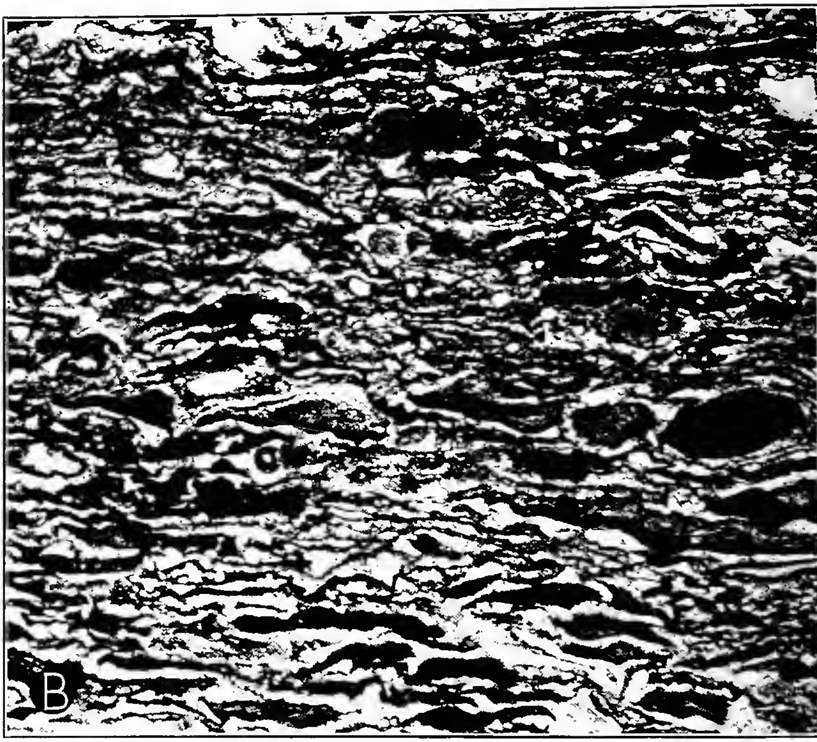


PLATE 1. B. The rock described under number 74 (3) in the well samples. The structure of this rock is such as to suggest that it may have been an oolite, from which much of the original material has been dissolved, causing the spherules to flatten. Vertical section, X 43.

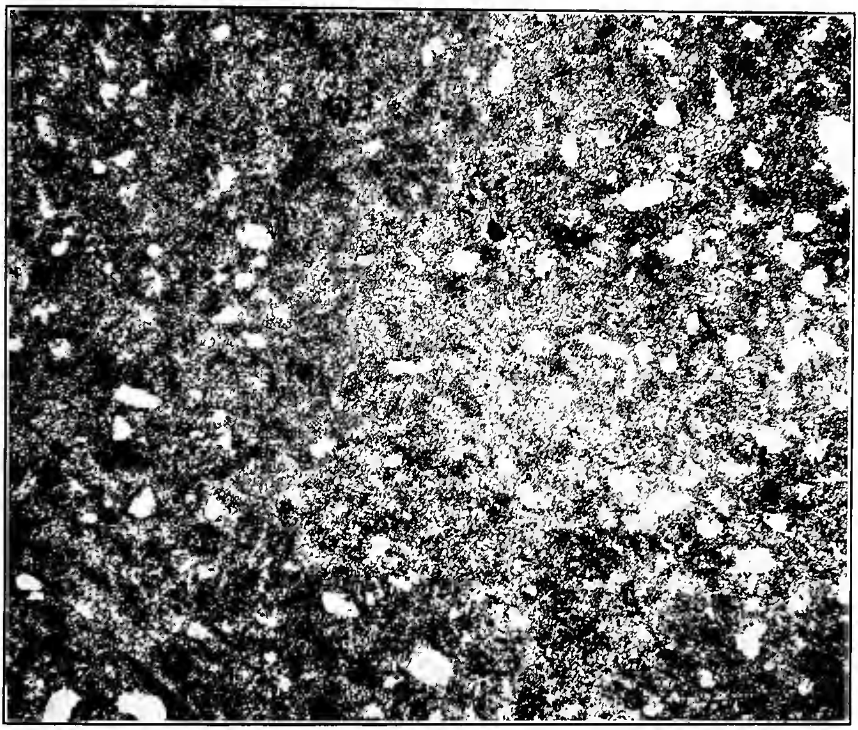


PLATE 2. Vertical section of dolomite from 1600 feet below surface. See description of sample number 77. X 40.

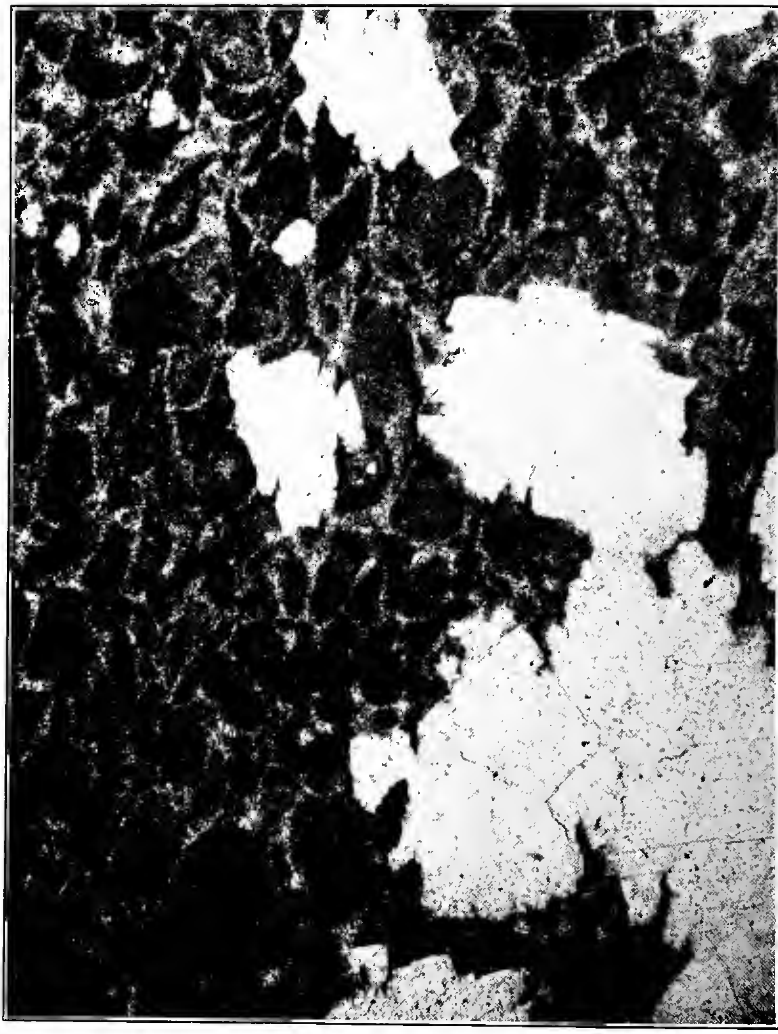


PLATE 3. Vertical section of oolitic dolomite, a considerable part of which has been replaced by anhydrite. The spherules are appressed and many appear to have been reduced by solution externally so as to conform to the shapes of adjacent spherules. For further description see sample 78. X 40.

(The vertical axis extends from left to right.)

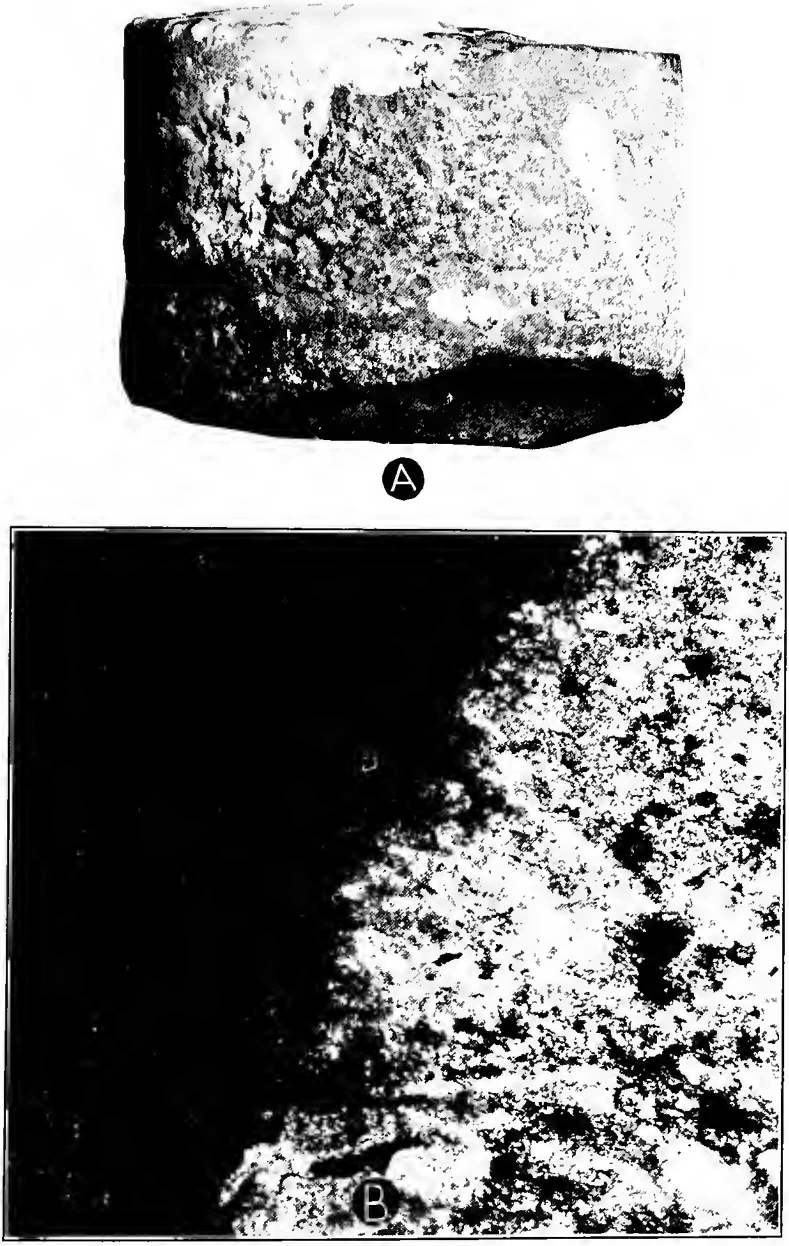


PLATE 4. A. Photograph of a piece of core from 2250 feet below the surface. Reduced to two-thirds natural size. Anhydrite and quartz appear light. For description see sample number 90.

B. Vertical section extending through part of a concretion of anhydrite with dim outlines of straight structures which probably are spicules of sponges. The rock, darker part of section, shows a dim stratification gently flexed upward against the anhydrite concretion. See description of sample 94. X 20.

PLATE 5. Vertical section of a dolomite showing the outlines of numerous organic fragments of small size imbedded in a matrix of more coarsely crystalline dolomite. The fragments show an oolitic coating and some oolitic spherules are present. A few of these are filled with anhydrite. The matrix appears light in the photograph. X 20. (The vertical axis extends from left to right.)

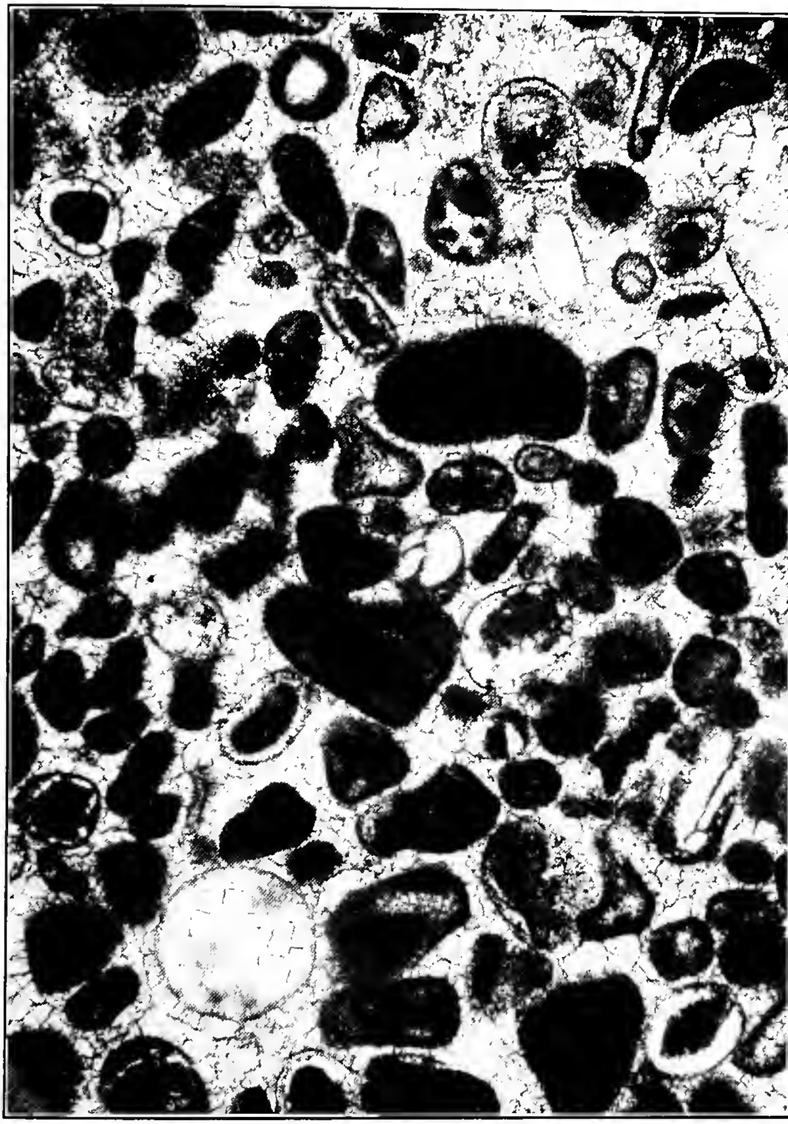


PLATE 6. Vertical section through another phase of the rock shown in plate 5. In this phase organic fragments are few, or almost absent, and the dolomite matrix is filled with oolitic spherules. The interiors of a few spherules are filled with anhydrite, and appear light in the plate. The darker appearing spherules consist of crystals of dolomite of very small size. X 20.

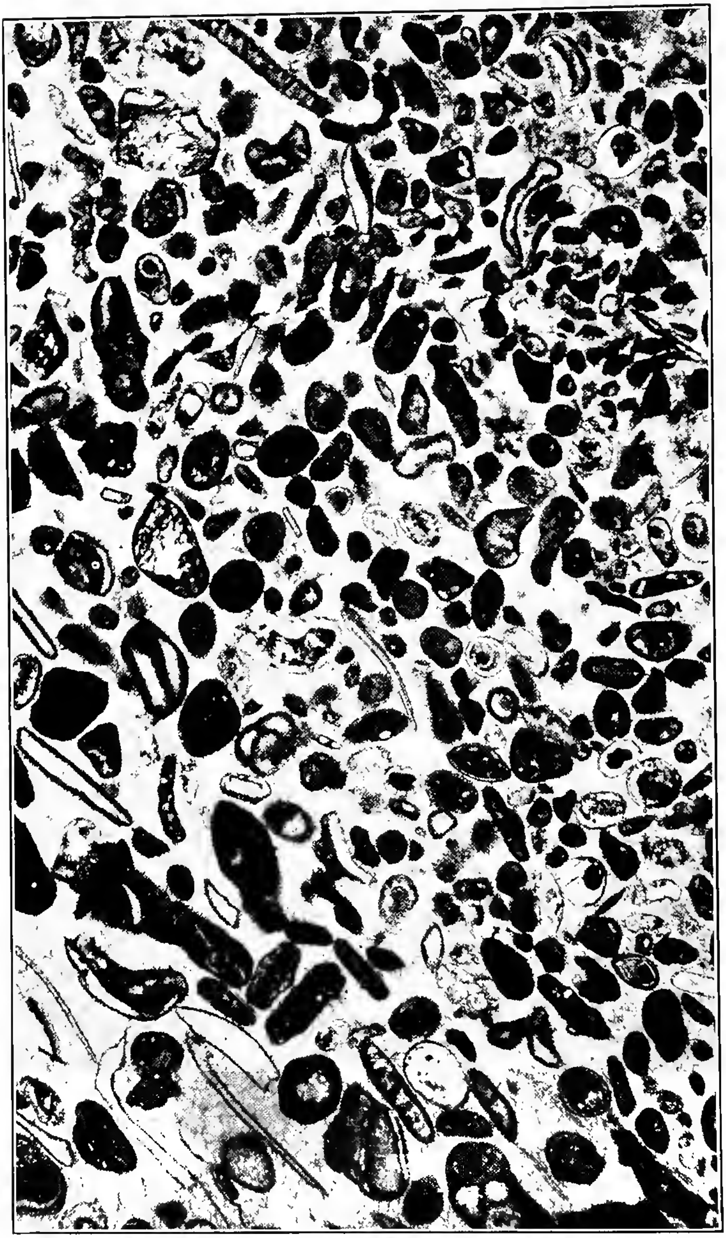
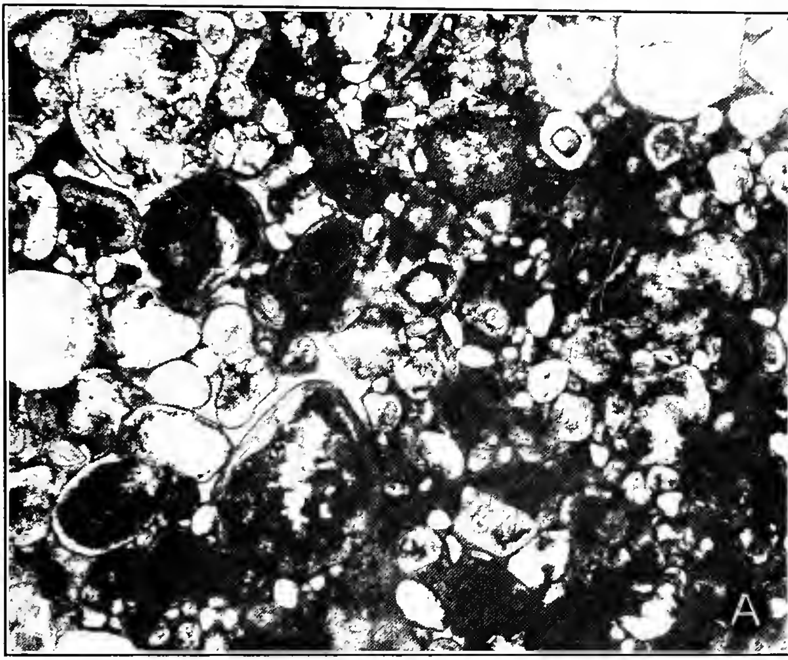


PLATE 7. Vertical section through a third phase of the dolomite shown in plates 5 and 6. This phase shows a mixture of oolitic spherules and organic fragments in a matrix of somewhat coarsely crystalline dolomite. Some few spherules are filled with dolomite crystals of the same size as the crystals in the matrix. X 20.



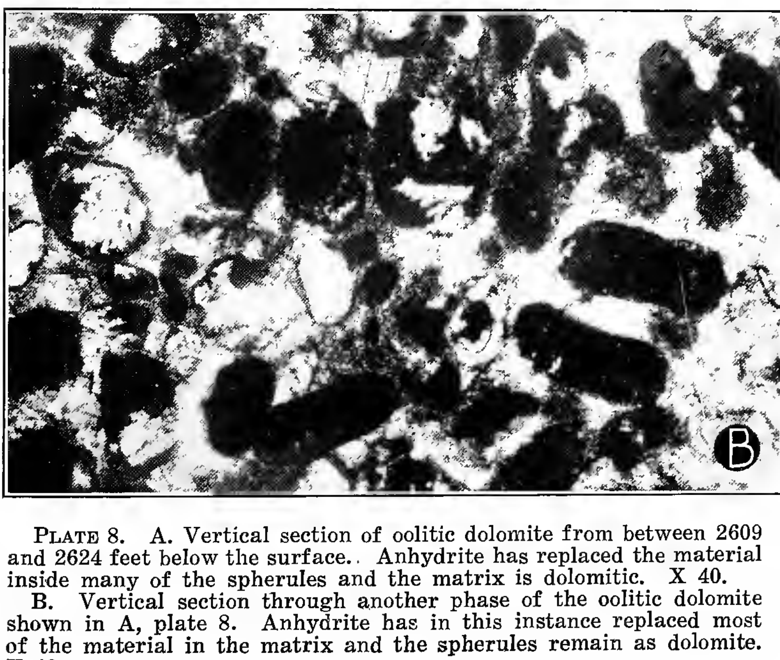


PLATE 8. A. Vertical section of oolitic dolomite from between 2609 and 2624 feet below the surface. Anhydrite has replaced the material inside many of the spherules and the matrix is dolomitic. X 40.

B. Vertical section through another phase of the oolitic dolomite shown in A, plate 8. Anhydrite has in this instance replaced most of the material in the matrix and the spherules remain as dolomite. X 40.

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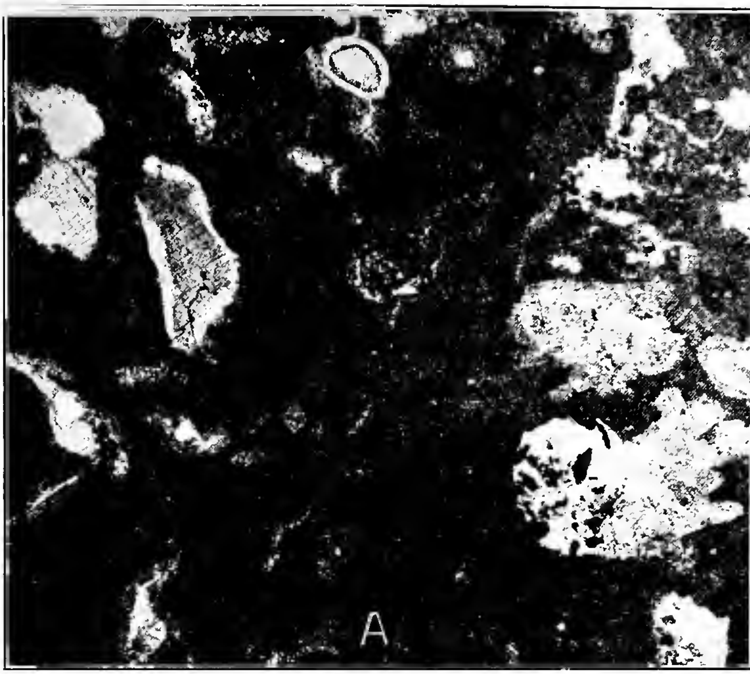
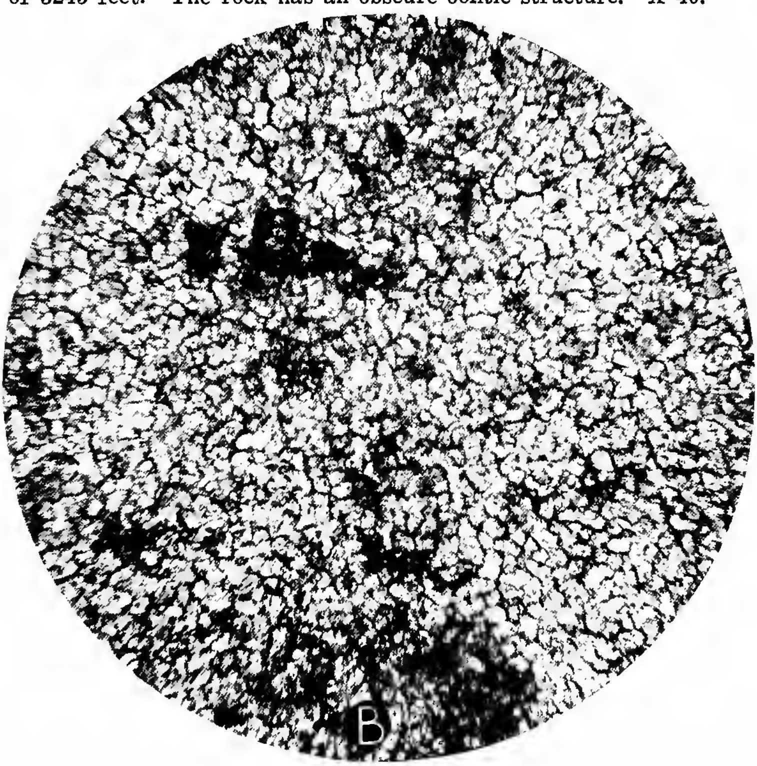
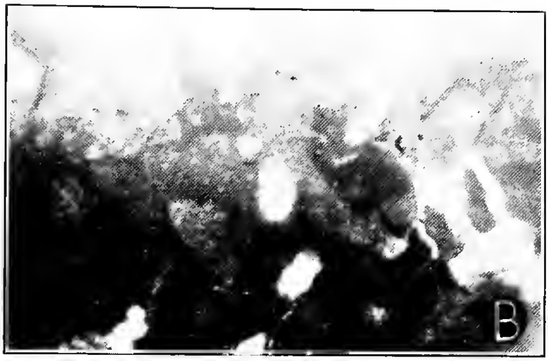


PLATE 10. A. Horizontal section of dolomite from near the depth of 3245 feet. The rock has an obscure oolitic structure. X 40.



B. Horizontal section of crystalline dolomite from near the depth

PLATE 11. Horizontal section of dolomite from near 3405 feet below the surface. The dolomite crystals are gathered into clusters which are separated by a reticular matrix containing some secondary anhydrite. This condition appears to be the beginning of a change, which in a more advanced stage has resulted in the production of a rock consisting mainly of anhydrite but with crystals of dolomite scattered like the centers of these clusters in the rock mass. The two phases are closely associated in the samples. X 80.



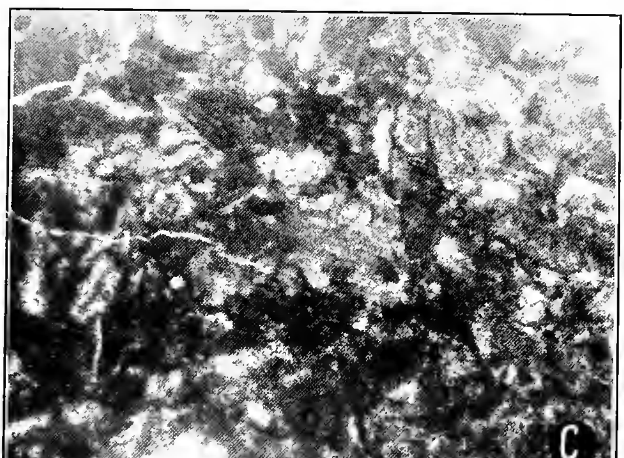
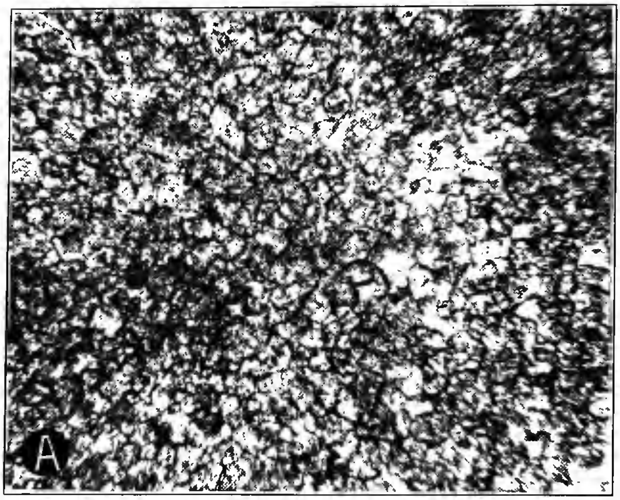


PLATE 12. B. Horizontal section of dolomite from near 3490 feet. For description see under sample number 213. The tubular structures are cut obliquely by the section. X 40.

C. Horizontal section of dolomite from near 3545 feet. Traces of organic fragments and of oolitic spherules are preserved in the texture of the rock. Some anhydrite is present. X 40.



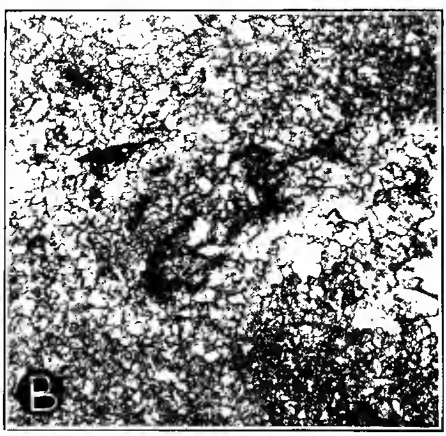
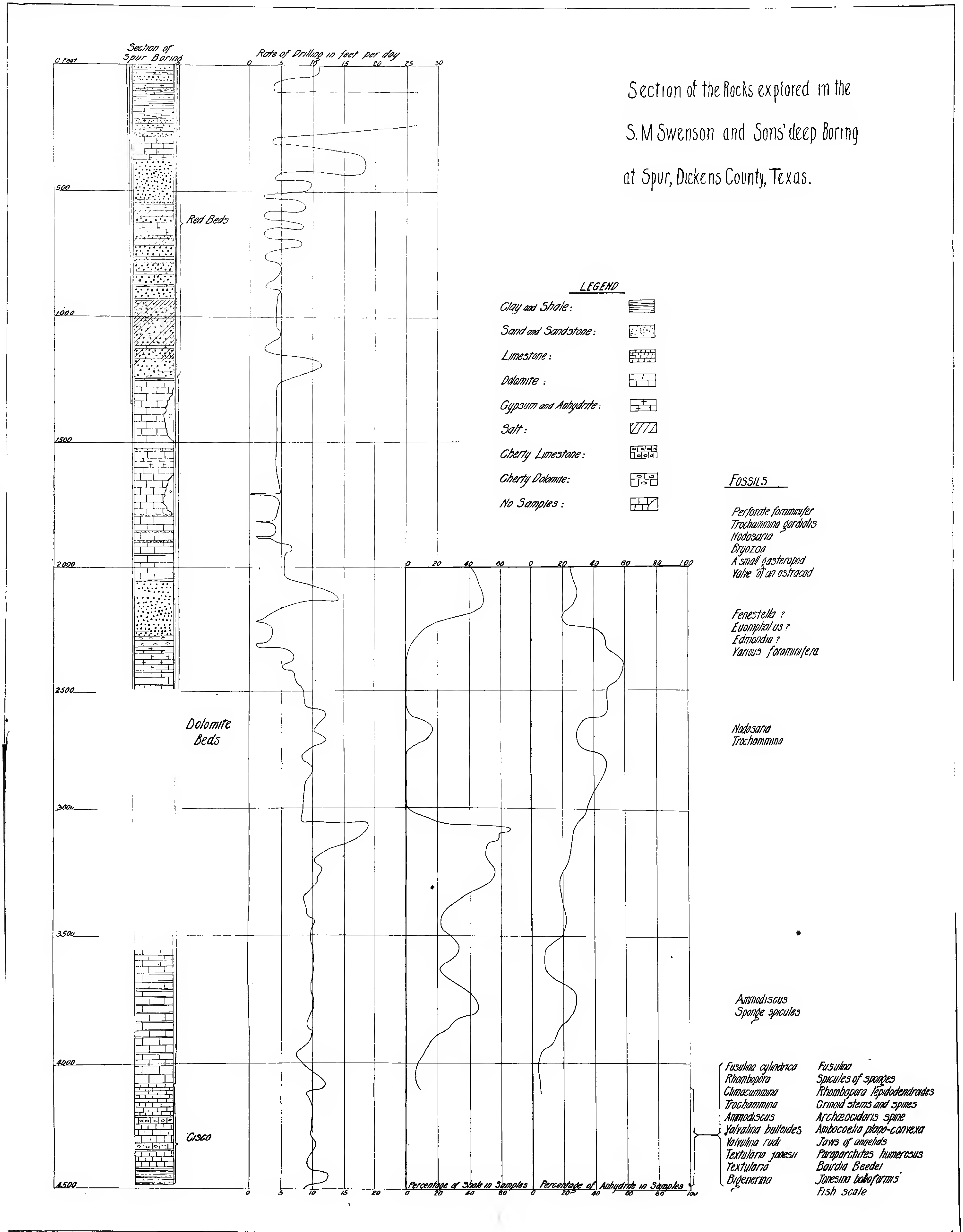


PLATE 13. A. Horizontal section of dolomite from near the depth of 4070 feet. The crystals are of uniform size. X 80.

B. Horizontal section of dolomite from near the depth of 4085 feet. This rock shows some streaks of bituminous material which appear dark in the section. X 80.

Plate 14. Horizontal section of limestone from near the depth of 4285 feet. The light areas are clear calcite, filling crinoidal and other organic fragments. X 40.


Section of the Rocks explored in the
S. M Swenson and Sons' deep Boring
at Spur, Dickens County, Texas.
Section of Spur Boring
Rate of Drilling in feet per day
0 Feet
500
1000
1500
2000
2500
3000
3500
4000
4500
Red Beds
Dolomite Beds
Cisco
LEGEND
Clay and Shale:
Sand and Sandstone:
Limestone:
Dolomite:
Gypsum and Anhydrite:
Salt:
Cherty Limestone:
Cherty Dolomite:
No Samples:
Percentage of Shale in Samples
Percentage of Anhydrite in Samples
FOSSILS
Perforate foraminifer
Trochammina gordialis
Nodosaria
Bryozoa
A small gasteropod
Valve of an ostracod
Fenestella ?
Euomphalus ?
Edmondia ?
Various foraminifera
Nodosaria
Trochammina
Ammodiscus
Sponge spicules
Fusulina cylindrica
Rhombopora
Climacammina
Trochammina
Ammodiscus
Valvulina bulloides
Valvulina rudi
Textularia jonesii
Textularia
Bigenerina
Fusulina
Spicules of sponges
Rhombopora lepidodendroides
Crinoid stems and spines
Archæocidaris spine
Ambocoelia plano-convexa
Jaws of annelids
Paraparchites humerosus
Bairdia Beedei
Jonesina bolloformis
Fish scale